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Upgrading Primary Tanks with Rotating Biological Contactors

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Fort Lee, NJ

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16. ABSTRACT

A one-year experimental program was conducted at Edgewater, New Jersey, to evaluate the concept of upgrading existing primary wastewater treatment plants to secondary treatment by the installation of rotating biological contactors (RBC's) in the primary sedimentation tanks.

The basic concept was to horizontally divide a primary sedimentation tank into two zones by installing an intermediate floor at mid-depth. Four RBS's were placed in the upper zone above the intermediate floor. This zone provided separate biological contact and treatment of the incoming wastes, while the lower zone functioned as a secondary sedimentation zone. Such a configuration would minimize the need for additional tankage and clarifiers, and would be especially suited to plants with limited space.

The experimental program was conducted in three phases over a full year. Three loadings were studied during the initial phase to determine the optimum system load that conformed with EPA standards. This loading was then evaluated under summer and winter conditions. Little difference in treatment efficiency was noted between summer and winter conditions, due primarily to the interactions of oxygen availability, mass transfer, and kinetic removal rates, and the impact of temperature on each.

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UPGRADING PRIMARY TANKS WITH ROTATING BIOLOGICAL CONTACTORS

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The study at Edgewater, New Jersey evaluated a novel application of rotating biological contactors for transforming a primary treatment plant into a secondary treatment facility. This project has contributed valuable technology in the wastewater treatment field.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

A one-year experimental program was conducted at Edgewater, New Jersey, to evaluate the concept of upgrading existing primary wastewater treatment plants to secondary treatment by the installation of rotating biological contactors (RBC's) in the primary sedimentation tanks. The Edgewater system is a combined sanitary/stormwater treatment facility, subject to significant operational variations related to stormwater flow.

The basic concept was to horizontally divide a primary sedimentation tank into two zones by installing an intermediate floor at middepth. Four RBC shafts (3.65 m diameter) were placed in the upper zone above the intermediate floor. This zone provided separate biological contact and treatment of the incoming wastes, while the lower zone, below the intermediate floor, functioned as a secondary sedimentation zone. Such a configuration would eliminate, or minimize, the need for additional tankage and clarifiers, and would be especially suited to plants with limited space. The system was preceded by grit removal and high rate primary clarification.

The experimental program was conducted in three phases over a full year. Three loadings were studied during the initial phase to determine the optimum system load that conformed with EPA standards. This loading was then evaluated under summer and winter conditions. Optimum loading conditions were found to be in the range of 9 to 11 $g/d/m^2$ (1.8 to 2.2 $lb/d/1,000$ ft^2), on a $TBOD_5$ basis. Influent organic concentrations were on the order of 140 mg/l $TBOD_5$ and 125 mg/l TSS. The study determined the need for pretreatment, whereby primary treatment overflow rates of 285 to 370 $m^3/d/m^2$ (7,000 to 9,000 gpd/ft^2) were found to provide adequate grit, trash, and floatables removal.

A steady-state fixed film kinetics model was utilized in the analysis of the RBC data. Little difference in treatment efficiency was noted between summer and winter conditions, due primarily to the interactions of oxygen availability, mass transfer, and kinetic removal rates, and the impact of temperature on each.

An important consideration in the design of the RBC/Underflow Clarifier system is the maximum utilization of the underflow clarifier zone. This may, in fact, be the limiting condition under certain cases when setting the hydraulic capacity of the unit. Suggested design criteria, operating conditions, and costs have been developed and are presented as an aid in evaluating this upgrading technique at other primary treatment plants.

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Mr. O. Karl Scheible is a Project Manager at Hydroscience, Inc., and was responsible for management of the Edgewater field program, data analysis and preparation of the final report. Mr. Thomas J. Mulligan is Technical Director of Hydroscience, Inc., and provided assistance in the management and the technical analysis of the overall project. Ms. Carlene Bassell, Hydroscience, Inc., supervised the field program and participated in the analysis and interpretation of the field data, and preparation of the final report. The guidance provided by Dr. James A. Mueller, Hydroscience, Inc., in the interpretation and use of the RBC Kinetic Model is also gratefully acknowledged.

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The assistance of Mr. Edward J. Opatken, EPA Project Officer, Municipal Environmental Research Laboratory, Cincinnati, Ohio, is gratefully acknowledged.

SECTION 1

INTRODUCTION

BACKGROUND

The Borough of Edgewater, New Jersey, operates a primary wastewater treatment facility which discharges into the Hudson River. In 1971, Edgewater was ordered by the State of New Jersey Department of Health to improve the degree of treatment being provided by the wastewater treatment plant to secondary treatment levels. Constrained by severe land limitations, several treatment alternatives were considered which would minimize plant expansion.

A process which indicated considerable promise involves the installation of rotating biological contactors (RBC) in the existing primary clarifiers. For proper functioning, an intermediate floor was required to be installed at mid-depth. After biological treatment of the raw wastewaters in the upper RBC sector, secondary clarification would be accomplished in the sector below the floor. However, because the proposed treatment scheme involved new concepts, the system needed to be evaluated in order to confirm its feasibility and to develop design and cost information. A program was then developed and financed by Edgewater to evaluate the RBC/Underflow Clarifier system with a prototype unit.*

The installation of the RBC/Underflow Clarifier system was completed in May 1973. The process evaluation was conducted over a period of three years by Edgewater personnel and results from these studies indicated that the modification of the primary clarifier to the two-tier treatment process could produce a secondary treatment effluent commensurate with U.S. Environmental Protection Agency effluent requirements. Realizing its potential, Edgewater officials sought, and received, a demonstration grant from the U.S. EPA to improve the existing facility and to continue the process evaluation under an intensive testing program.

OBJECTIVES AND SCOPE OF STUDY

Under the grant approved by the U.S. EPA, the primary objectives of the RBC/Underflow Clarifier pilot evaluation were as follows:

---

*Autotrol Corporation, Milwaukee, Wisconsin, claims the RBC/Underflow Clarifier concept to be a patented system.

(1) Establish the feasibility of upgrading existing primary sedimentation plants to meet the secondary treatment requirements of PL 92-500 through the installation of RBC units directly in primary clarifiers. (The U.S. EPA secondary treatment standards call for monthly average BOD_5 and SS concentrations in the effluent less than or equal to 30 mg/l, with percentage of removal being equal to or better than 85 percent, and weekly average BOD_5 and SS concentrations in the effluent less than or equal to 45 mg/l.)

(2) Evaluate the degree of pretreatment necessary to successfully operate an RBC system in this mode.

(3) Evaluate the effects of climatic conditions, diurnal flow, and total daily load and waste characteristic variations on process efficiency.

(4) Establish process and plant design parameters and capital and operating costs for the application of this upgrading technique to maximize the use of tankage and facilities at existing primary sedimentation plants.

The facility was modified and upgraded to assure proper operation and process control during the experimental program. A three-phase experimental program was then implemented:

Phase 1: Investigation of the RBC/Underflow Clarifier under a series of loading conditions encompassing a range sufficient to determine optimum operating conditions.

Phase 2: Evaluation of the system under warm (summer) temperature conditions at the predetermined optimum loading conditions.

Phase 3: Evaluation of the system under cold (winter) temperature conditions at the predetermined optimum loading conditions.

The results of the experimental program were then evaluated to determine process kinetic parameters and overall treatment performance. Process and plant design considerations were investigated and an economic analysis was made of the suggested design alternatives.

PARTICIPANTS AND COORDINATION

The U.S. EPA Demonstration Grant was awarded to the Borough of Edgewater to further evaluate the RBC/Underflow Clarifier system as installed in its treatment plant. Edgewater retained the firms of Hydroscience, Inc., Westwood, New Jersey, and Clinton Bogert Associates, Fort Lee, New Jersey, as its engineering representatives to carry out the scope of work detailed in the grant. Edgewater personnel were responsible for providing labor for upgrading the plant, and the daily operation and maintenance of the system during the experimental program.

Hydroscience, Inc. was responsible for the implementation and conduct of the experimental study, and the analysis and interpretation of all data collected during the program. Hydroscience personnel conducted the on-site analysis of samples, performed all field measurements, and documented the results of all analyses and field measurements.

Clinton Bogert Associates, as the Borough of Edgewater Engineers, assisted Edgewater in the administration of the grant and conducted facility evaluation, design, drafting and construction supervision associated with the modification and upgrading of the plant. Additionally, they conducted the economic analysis of the RBC/Underflow Clarifier process, based on the process design evaluation conducted by Hydroscience.

SECTION 2

CONCLUSIONS

A one-year experimental program was conducted at Edgewater, New Jersey, to evaluate the concept of upgrading existing primary wastewater treatment plants to secondary treatment by the installation of Rotating Bological Contactors (RBC) in the primary sedimentation tanks. The following summarizes the results of the experimental program and conclusions derived from their analysis.

The average wastewater characteristics during the one-year experimental program may be summarized as follows:

Flow		9920	m^3/day (2.6 mgd)
BOD_5	Total	144	mg/l
	Soluble	80	mg/l
COD	Total	350	mg/l
	Soluble	176	mg/l
TSS		169	mg/l
TKN		26	mg/l
NH_3-N		13	mg/l

The experimental program was conducted in three phases. The first phase evaluated the system over a series of loading conditions. Based on the results of the Phase 1, an appropriate loading was selected for evaluation under warm temperature (Phase 2) and cold temperature conditions (Phase 3). The following briefly summarizes the results from these study periods.

		Phase 1		Phase 2	Phase 3
	Low Load	Moderate Load	High Load	(Warm Temp.)	(Cold Temp.)
Flow m^3/day	1,060	1,440	2,520	1,550	1,490
(mgd)	(0.3)	(0.4)	(0.7)	(0.4)	(0.4)
Hydraulic Loading					
m^3/d/m^2	0.058	0.079	0.14	0.085	0.081
(gpd/ft^2)	(1.4)	(1.9)	(3.4)	(2.1)	(2.0)
Temperature, (^{o}C)	13	17	23	26	11
Influent					
TBOD$_5$ (mg/l)	90	155	144	130	154
SBOD$_5$ (mg/l)	54	96	77	87	79
TBOD$_5$ Loading					
g/d/m^2	5.3	11.7	19.7	11.4	12.9
(lbs/d/Kft^2)	(1.1)	(2.4)	(4.0)	(2.3)	(2.6)
SBOD$_5$ Loading					
g/d/m^2	2.8	7.7	10.4	8.3	7.4
(lbs/d/Kft^2)	(0.6)	(1.6)	(2.1)	(1.7)	(1.5)
Effluent					
TBOD$_5$ (mg/l)	15	23	55	29	33
SBOD$_5$ (mg/l)	10	22	31	23	24
Effluent					
TSS (mg/l)	24	23	58	30	24

A fixed film kinetic model developed by Hydroscience, Inc. and specifically adapted to the RBC treatment process, was utilized in evaluating the results of the program. The model was verified with interstage data collected regularly, and was demonstrated capable of predicting system performance over a range of hydraulic and organic loading conditions using a single set of kinetic coefficients. The match of observed data and model predictions indicated that hydraulic and mass transfer components of the model responded correctly to system variations.

Design nomographs were developed using the RBC kinetic model. The curves represent single stage solutions dependent on influent dissolved oxygen, soluble BOD$_5$ and hydraulic loading. Their iterative use allows prediction of removal efficiencies in multi-stage systems. As a check, the curves were used to predict effluent quality under conditions evaluated during the experiemental program. The design curves successfully predicted the average effluent soluble BOD$_5$ observed during each of the five operating conditions.

Based on the overall evaluation, the following observations are presented:

1. The RBC/Underflow Clarifier concept was demonstrated to be an effective secondary treatment process, capable of meeting NPDES secondary treatment effluent requirements of 30 mg/l $TBOD_5$ and TSS, or 85 percent $TBOD_5$ and TSS removal, whichever provides the greater degree of treatment.

   The peak monthly loading at Edgewater controlled the process design. The influent peak monthly total BOD_5 was 215 mg/l, with a corresponding soluble BOD_5 equal to 130 mg/l. In order to meet the 85 percent $TBOD_5$ removal secondary treatment requirement, the limiting organic loadings for the RBC sector were determined to be 10.4 g $TBOD_5/d/m^2$ (2.1 lb/d/1000 ft^2) and 6.5 g $SBOD_5/d/m^2$ (1.3 lb/d/1000 ft^2). The process design curves project a total RBC media surface area requirement of 246,000 m^2 (2.65×10^6 ft^2) for the Edgewater system.

2. Pretreatment of the raw wastes was required throughout the study period to remove grit, trash, and floatables. Effective pretreatment can be provided by high rate sedimentation, with average overflow rates between 285 and 370 $m^3/d/m^2$ (7,000 to 9,000 gpd/ft^2). Average overall removals between 20 and 25 percent for TSS and 10 to 15 percent for Total COD were achieved. Minimal removals of $TBOD_5$ were noted. Rough screening was necessary to remove large fibrous material which passed through the high rate primary treatment sector.

3. Tracer analyses were conducted and characterized the hydraulics through the RBC/Underflow Clarifier system. The results indicated that each RBC stage, as defined by baffle placement, behaved as a completely mixed tank. A time-variable analysis of completely mixed tanks in series adequately described the hydraulics in the system, and matched observed lithium tracer data.

   The combined turnaround and fourth shaft sectors, without a baffle separation, behaved as a completely mixed tank. The mixing characteristics of the turnaround sector reduced the effective volume of the clarifier by approximately 25 percent. At Edgewater, this was interpreted as a 25 percent reduction in the effective clarifier surface area from 72.8 m^2 (784 ft^2) to 54.6 m^2 (588 ft^2).

4. The Edgewater system is a combined sanitary/stormwater treatment facility, subject to significant variations related to stormwater flow. Diurnal flow variations were approximately 1.5 to 1.0 maximum to average and 0.5 to 1.0 minimum to average. Studies to estimate diurnal variation in organic and suspended solids concentrations determined a maximum to average ratio of 1.69 for Total COD and 2.0 for Total suspended solids. The diurnal variation of pollutant concentrations was found to lag the diurnal waste flow

pattern, resulting in greater diurnal variations in waste loading than occurred with the flow. The diurnal pattern of effluent concentrations of measured pollutants (COD and TSS) was found to mirror the influent pattern. A 24-hour oxygen profile of the fourth stage showed marked variation consistent with the waste load pattern imposed on the RBC system.

5. The overall organic removal efficiency of the RBC system was limited by oxygen availability as determined by the Kinetic model. Oxygen utilization curves developed from COD balances and the model indicated that the system reached a limiting condition in its ability to transfer oxygen at the higher influent organic loading rates.

6. The overall seasonal effects were minimal based on the evaluation of the system under summer and winter conditions. The temperature differential experienced was 15°C. Although temperature affects several mechanisms involved in the kinetics of the fixed film process, the minimal overall impact experienced over this large temperature differential was due to compensating influences of the various parameters affected by temperature. Higher removal rates and diffusivities experienced in the summer were offset by the low dissolved oxygen levels and the lower dissolved oxygen saturation value. In the winter, the lower kinetic removal rates were compensated by high influent dissolved oxygen levels and a higher dissolved oxygen saturation value. Since dissolved oxygen penetration into the biofilm was found to be the limiting factor in overall treatment efficiency, imposition of high dissolved oxygen concentrations and/or higher dissolved oxygen saturation values effectively increased the oxygen driving force, increasing the active film thickness, and resulting in greater substrate removal.

7. Pre-aeration was investigated using the kinetic model. Since the system at Edgewater is characterized by decreasing organic load with progressive staging, the provision of pre-aeration to the influent of the RBC/Underflow process would not have a significant impact on removal efficiency.

   Interstage aeration would achieve greater substrate removals. At Edgewater, model simulation of interstage aeration, while allowing greater substrate removal, showed it would not significantly change the overall process design requirements.

8. Filamentous organisms appeared intermittently during the warm temperature months (May through September). The organisms were visually identified as beggiatoa, which are white to clear filamentous bacteria, and form large white patches on the surface of the biofilm. Beggiatoa metabolize sulfide to elemental sulfur. Under low dissolved oxygen levels during the warm temperature period, sulfate may be utilized by the bacteria as an alternate oxygen

source, resulting in the production of sulfide, which in turn is conducive to growth of beggiatoa.

The recurring appearances of filamentous organisms did not appear to affect the treatment efficiency of the system at Edgewater. During one period, hydrogen peroxide was evaluated as a control mechanism. At a dosage level of 40 mg/l, the filamentous growth appearing on all four stages was eliminated within a period of 48 hours.

9. Underflow baffles effectively stage the RBC system into a series of completely mixed tanks. Baffling also created higher velocities along the intermediate floor and minimized solids accumulation. At an initial baffle clearance of 15.2 cm (6 in), velocities were not sufficient to prevent considerable accumulations on the floor. Reduction of the baffle clearance to 5 cm (2 in) effectively prevented further solids accumulation.

10. Inventories of influent and effluent solids and wasted solids were kept on a continuing basis during the experimental program. A linear correlation of total suspended solids wastage as a function of $TBOD_5$ loading to the system was determined. On the average, biological solids growth was estimated to be 0.38 g SS_p/g BOD_5 removed.

11. A correlation of effluent TSS and underflow clarifier overflow rate was constructed on data collected over the entire program. The correlation implies an allowable overflow rate between 22 and 26 $m^3/d/m^2$ (550 and 650 gpd/ft^2) to obtain an effluent TSS less than 30 mg/l. This correlation assumed an effective intermediate floor surface area of 54.6 m^2 (588 ft^2).

12. Chemical addition studies showed that ferric chloride addition to the fourth stage effluent would effectively improve solids settleability.

    A full-scale evaluation of ferric chloride at dosage levels between 20 and 70 mg/l was not successful when a rapid mix period was not provided prior to clarification. Tests indicated that an initial rapid mix period must be provided to assure contact of the liquor with the coagulant. Settling tests of a fourth stage mixed liquor sample, dosed with 20 mg/l ferric chloride and rapidly mixed for five minutes, showed that effluent suspended solids levels between 15 and 20 mg/l could be expected over an effective overflow range of 20 to 40 $m^3/d/m^2$ (490 to 980 gpd/ft^2).

13. Cost analyses were conducted of alternative design sequences at Edgewater. These costs are based on conditions at Edgewater, including 1977 loading estimates and removal rate coefficients determined during the field program. It is important to realize that costs will be sensitive to these parameters. Thus higher

removal rate coefficients would induce lower capital and operating costs.

In the first alternative, one of the existing five primary sedimentation tanks would be converted to a high rate pretreatment tank, while the remaining four would be converted to the RBC/Underflow Clarifier process. New tankage (approximately equivalent to the existing tankage) was then added to provide the requirement for additional surface area in both media and underflow clarification to meet secondary effluent objectives. The unit cost for this upgrading procedure is estimated to be 0.077 $\$/m^3$ ($0.29/1,000 gal), considering both operation and maintenance and amortized capital costs.

An alternative considered was high rate pretreatment, standard RBC tankage (no underflow clarifier), and utilization of the existing primary tanks for secondary clarification. The unit cost of this scheme is estimated to be $\$0.061/m^3$ ($0.23/1,000 gal), which is less than the above RBC/Underflow Clarifier. Land requirements (included in these costs), however, would be 50 percent higher.

SECTION 3

RECOMMENDATIONS

1. Close attention must be given to the hydraulics of the RBC/Underflow Clarifier system. The staging should be adequately baffled to assure each stage is completely mixed. The turnaround sector volume should be minimized since it adds little to the overall treatment effectiveness.

2. Pretreatment should be provided to prevent trash, grit and heavy solids material from reaching the RBC system. This may be accomplished by microstrainers, swirl separation, or high rate primary sedimentation sectors.

3. Process design modifications should address the provision of chemical treatment or an alternate procedure to enhance solids capture. Alternative methods may include microscreens or rapid sand filters. This would allow increased soluble BOD_5 effluent requirements and an increase in the design loading to the RBC system.

SECTION 4

DESCRIPTION OF EDGEWATER TREATMENT PLANT AND RBC FACILITY

EDGEWATER WASTEWATER TREATMENT PLANT

The Borough of Edgewater is in northeastern New Jersey, one kilometer (0.6 miles) south of the George Washington Bridge on the western bank of the Hudson River, across from New York City. The 11,000 m^3/day (3 mgd) treatment plant provides primary treatment for the wastewater from within its own boundaries, as well as from most of the neighboring Borough of Cliffside Park.

Figure 1 shows a plan of the existing plant site. The major facilities include an Administration Building, Pump House, comminutor, grit collector, five primary settling tanks, Chlorine Building and outfall sewer. Sludge is processed in two anaerobic sludge digesters and two vacuum filters. A flash dryer is also available although not presently used. Land is limited, comprising only 0.6 ha (1.5 acres) of usable area.

The average daily flow from Edgewater and Cliffside Park is approximately 9,800 m^3/day (2.6 mgd). The sewer system is combined, which results in peak storm flows exceeding 27,000 m^3/day (7.2 mgd), the maximum flow capacity of the recording meter. The industrial wastewater flow is estimated at 700 m^3/day (0.18 mgd) or seven percent of the average flow.

Table 1 presents average values of the raw wastewater for the one-year testing period, March 1977 through February 1978.

TABLE 1. RAW SEWAGE COMPOSITION

	Average	Range of values
Flow, m^3/day (mgd)	9,920 (2.6)	4,540-31,800 (1.2-8.4)
BOD_5 total, mg/l	144	50-573
BOD_5 soluble, mg/l	80	22-188
COD total, mg/l	350	128-772
COD soluble, mg/l	176	67-280
TSS, mg/l	169	36-373
TVSS, mg/l	137	44-206
TKN total, mg/l	26	10- 41
TKN soluble, mg/l	22	9- 31
NH_3-N, mg/l	13	3- 21

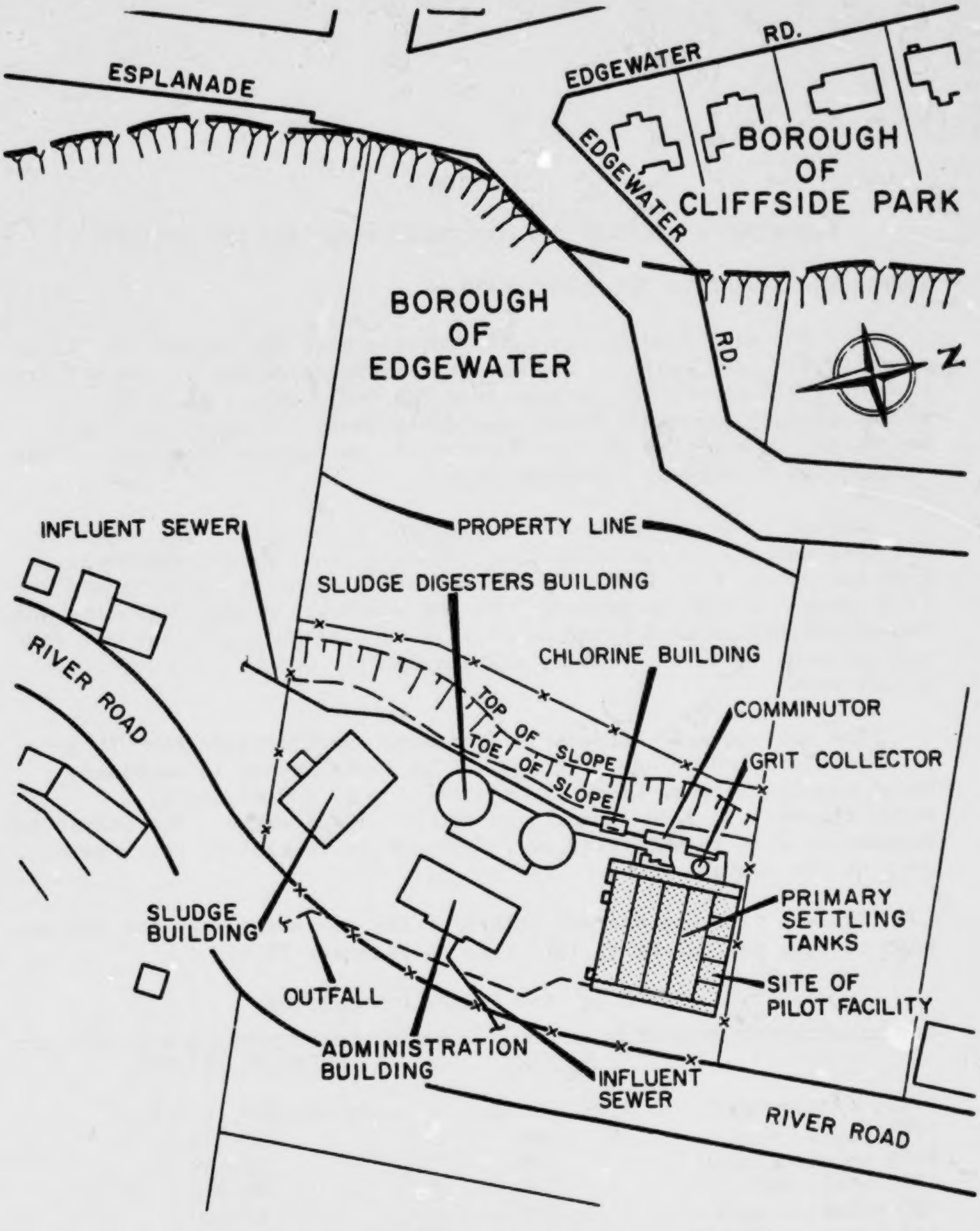

ESPLANADE
EDGEWATER RD.
EDGEWATER RD.
BOROUGH OF CLIFFSIDE PARK
BOROUGH OF EDGEWATER
N
PROPERTY LINE
INFLUENT SEWER
SLUDGE DIGESTERS BUILDING
CHLORINE BUILDING
RIVER ROAD
TOP OF SLOPE
TOE OF SLOPE
COMMINUTOR
GRIT COLLECTOR
PRIMARY SETTLING TANKS
SLUDGE BUILDING
SITE OF PILOT FACILITY
OUTFALL
ADMINISTRATION BUILDING
INFLUENT SEWER
RIVER ROAD
0
100
200
300 FT.

Figure 1. Wastewater treatment plant site.

DESCRIPTION OF RBC/UNDERFLOW CLARIFIER TEST MODULE

Primary Settling Tank No. 5 was converted to evaluate the RBC/ Underflow clarifier concept. Raw wastewater, after passing through the comminutor and grit collector, was pumped from a point located 3.51 m (11.5 ft) from the influent side of Settling Tank No. 3. The layout of the plant and test module is shown on Figure 2.

Figure 3 shows a cross-section of the primary settling tank before being converted. The effluent channel of Tank 5 was modified to incorporate an influent channel and a separate treated effluent channel. A flow meter was installed in the effluent channel. The top of Tank No. 5 was structurally modified and the RBC units were installed with the bearing blocks on top of the walls. Covers were installed over the RBC units to protect the media and the biomass from the weather.

Figure 4 shows a cross-section of Tank 5 after conversion. The intermediate floor was installed to provide an underflow clarifier with a water depth of 1.42 m (4 ft 8 in). Four RBC units with diameters of 3.61 m (12 ft) were installed in the 21.34 m (70 ft) long by 4.37 m (14 ft 4 in) wide tank with a water depth of 1.22 m (4 ft) above the intermediate floor.

The RBC units are made of high-density polyethlyene. Stages one, two and three each have a surface area of 1,220 m^2/m of shaft length (4,000 ft^2/ft) and stage four has a surface area of 1,830 m^2/m (6,000 ft^2/ft). Each of the four shafts is 4.1 m (13 ft 5 in) long. The unit was immersed 1.07 m (3 ft 6 in) which provides a total effective wetted surface area for the four shafts of 18,200 m^2 (196,500 ft^2). The small portion of the central surface free of microorganisms represents 17 percent of the total surface area.

Employment of the RBC unit involves both mechanical and biological processes. As the RBC unit rotates in its designed position, the media are passed through the wastewater, carrying a film of wastewater upward above the surface. The wastewater contacts the biomass while trickling across the media. Microorganisms normally found in wastewater will adhere to the surface of the media and grow, eventually covering the entire surface. Organic material is provided to the biomass as the media pass through the wastewater, while oxygenation is accomplished when the media pass through the atmosphere. This continual rotation provides the necessary materials for the biological reactions which reduce the BOD of the wastewater. Meanwhile, the shearing action of the wastewater on the biomass strips some of the growth from the media. Sloughed biomass and primary solids are swept along the intermediate floor toward the hopper end of the clarifier (see Figure 4) by the combined rotational effect of the discs and fluid velocity. At the influent end of the clarifier, some of the solids drop off the end of the intermediate floor into the sludge hopper. The biologically treated wastewater now reverses direction and flows under the intermediate floor back toward the effluent end of the clarifier where it is discharged. Additional solids settling out during this clarification step are scraped into the sludge hopper by the sludge collector mechanism.

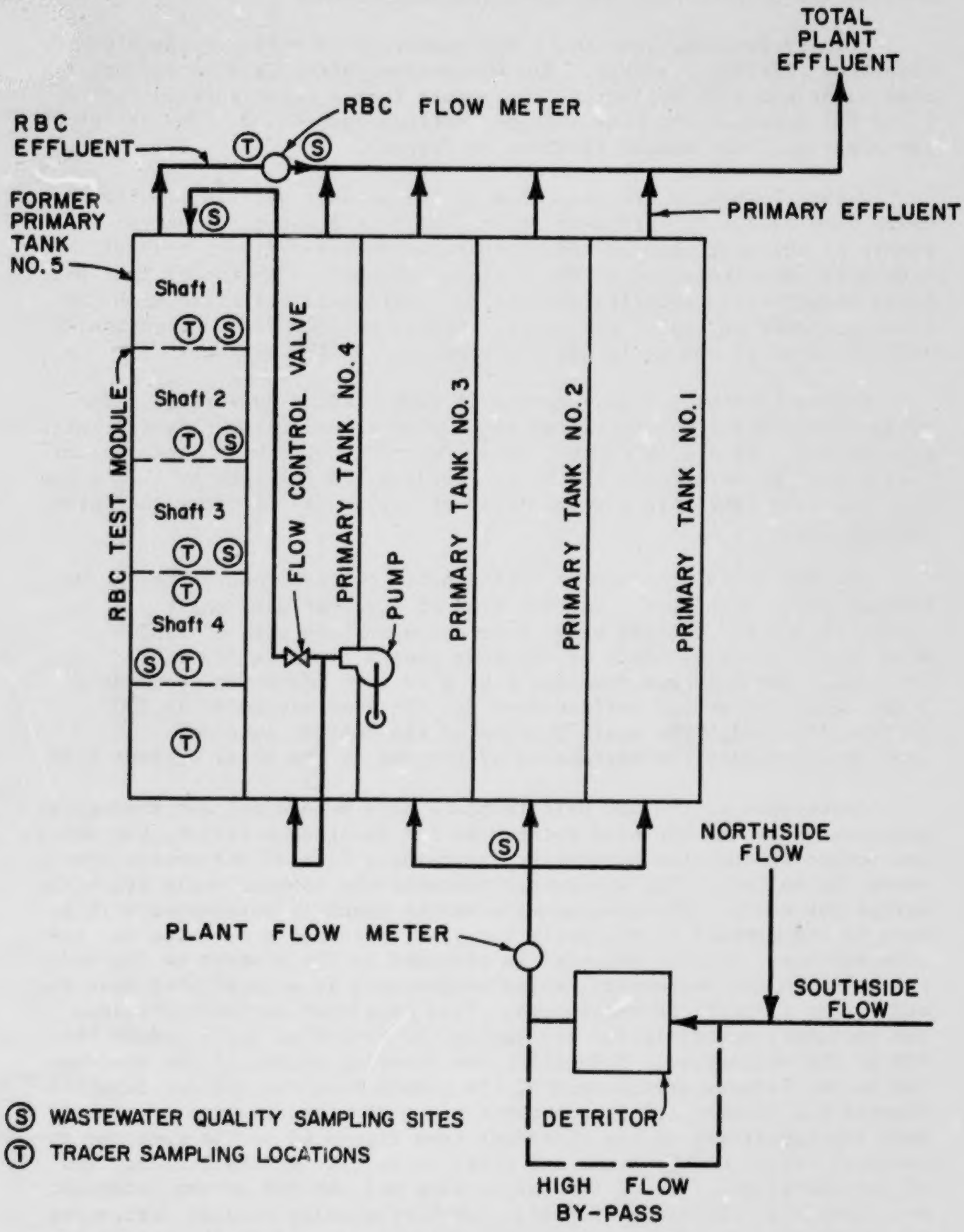

TOTAL PLANT EFFLUENT
RBC FLOW METER
RBC EFFLUENT
T
S
FORMER PRIMARY TANK NO. 5
S
PRIMARY EFFLUENT
Shaft 1
T S
Shaft 2
T S
Shaft 3
T S
T
Shaft 4
S T
T
RBC TEST MODULE
FLOW CONTROL VALVE
PRIMARY TANK NO. 4
PUMP
PRIMARY TANK NO. 3
PRIMARY TANK NO. 2
PRIMARY TANK NO. 1
S
NORTHSIDE FLOW
PLANT FLOW METER
SOUTHSIDE FLOW
DETRITOR
HIGH FLOW BY-PASS
S WASTEWATER QUALITY SAMPLING SITES
T TRACER SAMPLING LOCATIONS

Figure 2. Plant flow schematic.

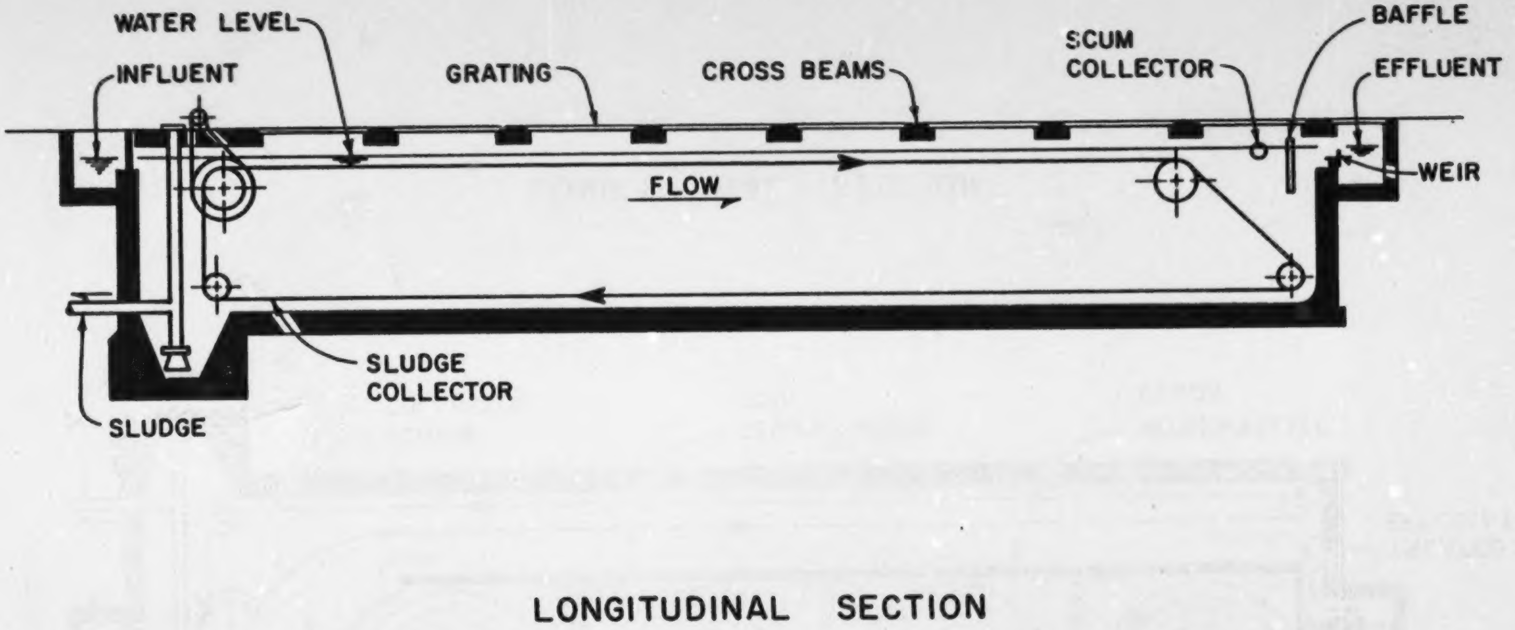
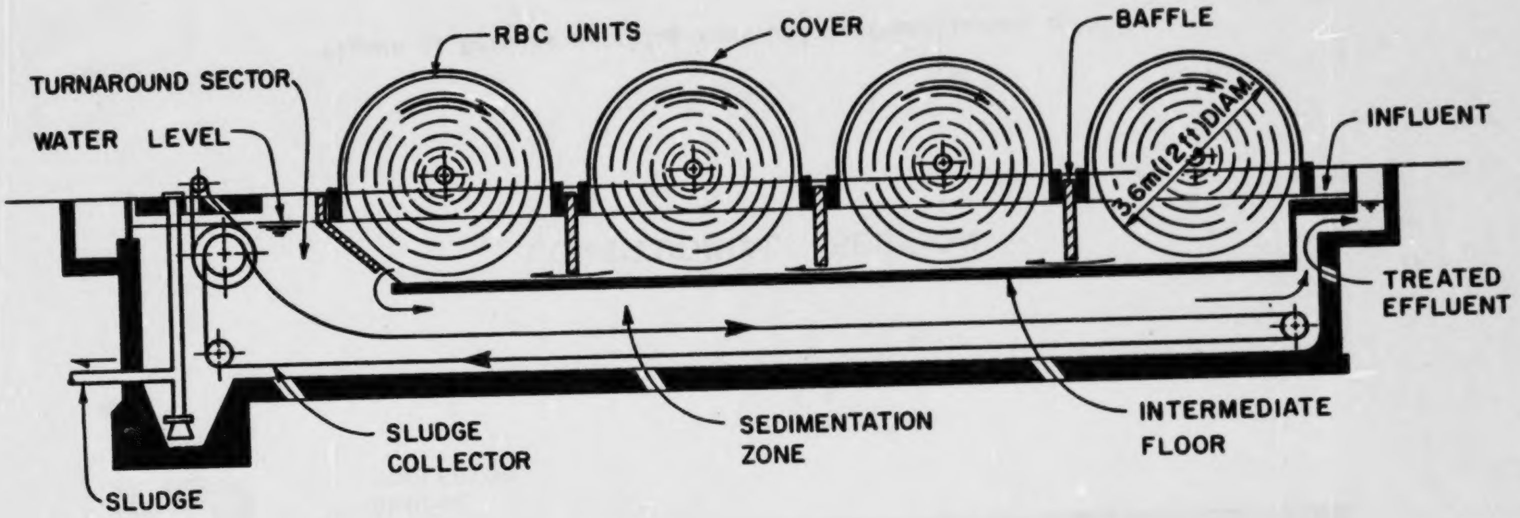

WATER LEVEL
INFLUENT
GRATING
CROSS BEAMS
SCUM COLLECTOR
BAFFLE
EFFLUENT
WEIR
FLOW
SLUDGE COLLECTOR
SLUDGE
LONGITUDINAL SECTION

Figure 3. Primary settling tank before installation of RBC.


RBC UNITS
COVER
BAFFLE
TURNAROUND SECTOR
WATER LEVEL
INFLUENT
3.6m(12ft)DIAM.
TREATED EFFLUENT
SLUDGE COLLECTOR
SEDIMENTATION ZONE
INTERMEDIATE FLOOR
SLUDGE

LONGITUDINAL SECTION

Figure 4. RBC testing unit.

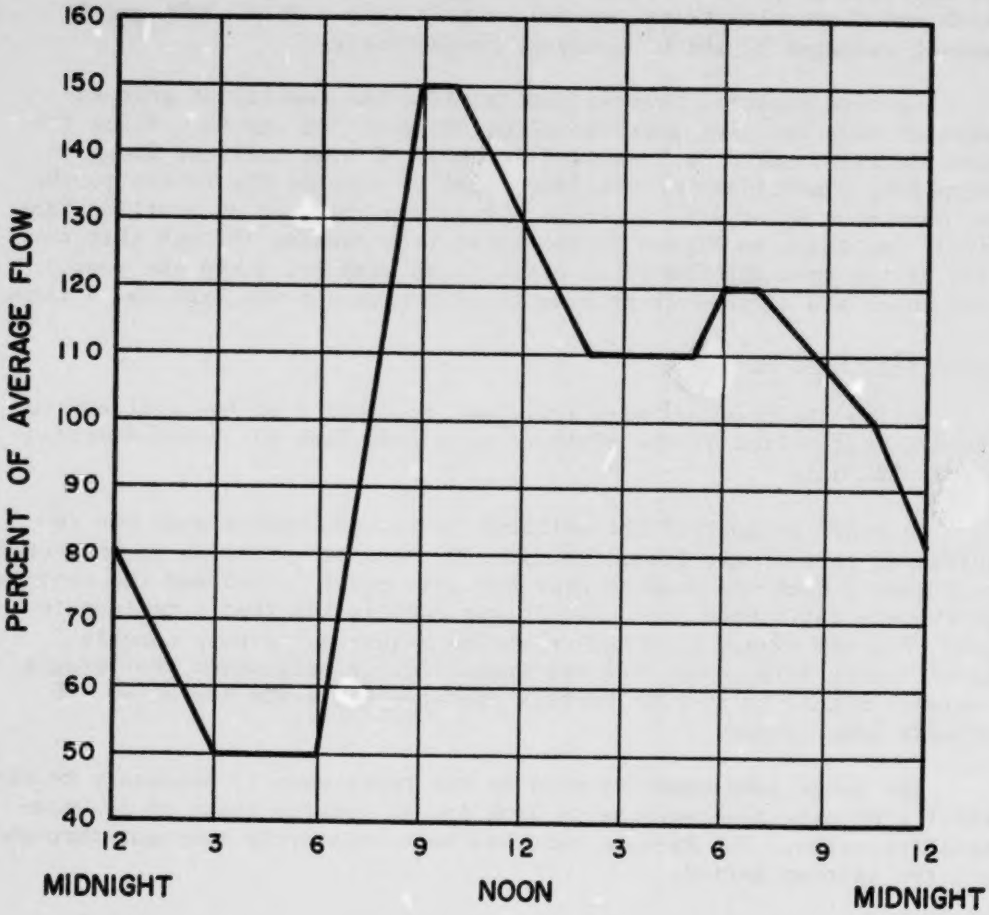


Figure 5. Hourly variation of wastewater flow.

Pretreatment

The configuration of the testing unit under the previous evaluation work provided primary settling in Tank No. 4. The overflow rate was approximately 40.7 $m^3/d/m^2$ (1,000 gpd/ft^2) with grit, trash and floatables being removed in this tank. Total BOD_5 and SS removal averaged 37 and 61 percent, respectively.

The test program, however, anticipated the removal of grit and trash without removing substantial portions of BOD and SS. Since the plant detritor could be by-passed at times of high influent flows to the plant, a modification was introduced to provide the intake to the RBC pump at a point 3.51 m (11 ft 6 in) from the head of Settling Tank No. 3. As shown on Figure 2, the total flow passing through this portion of the tank was the total effluent of Tank No. 3 and the pumped flow which was divided to provide the RBC flow and the Tank No. 4 flow.

Controlled Pumping

During the previous work there was no control of the influent to the RBC unit. Part of the effluent flow from Tank No. 4 was diverted to the RBC unit.

In order to control the influent to the RBC unit a pump was required as part of the installation. The diurnal variation is presented in Figure 5 with the peak to average ratio equal to 1.5 and the minimum to average ratio equal to 0.5. It was anticipated that a maximum test flow of 5,680 m^3/day (1.5 mgd) might be required. A pump capable of providing this large flow was installed. A programmer providing a variable signal to an electrically operated valve was installed, to provide lower flows.

The large pump capacity used in the tests made it necessary to install a by-pass feeding pipe to Tank No. 4, located ahead of the controlling valve. The by-pass rate was kept relatively constant throughout the testing period.

Influent Channel

An influent weir was built in the influent channel to the RBC to distribute the flow uniformly. Additionally, screens were attached to this influent channel to catch large fibrous materials.

Other Improvements

The intermediate floor and the influent channel were adequately caulked to prevent leakage and/or exchange of effluent and incoming wastewaters. Additionally, a fourth stage baffle was installed in June 1977 to segregate the turnaround sector from the 4th stage of the treatment sector.

SECTION 5

EXPERIMENTAL AND ANALYTICAL PROGRAM

Phase 1: Load Evaluations

Phase 1 of the experimental program studied the RBC system performance over a wide range of loading conditions. The initial loading was set relatively low to ensure an effluent quality greater than EPA requirements. EPA secondary treatment standards presently call for 85 percent BOD_5 and TSS removal or monthly average BOD_5 and SS concentrations less than or equal to 30 mg/l. Maximum weekly average BOD_5 and SS concentrations must be less than or equal to 45 mg/l. The loading was then increased to yield an effluent quality approximately equivalent to EPA standards. The third and final loading condition was chosen to stress the RBC system, i.e. violate the 30/30 BOD_5/SS standards.

Under actual operation, the low loading condition was run for approximately two weeks. The moderate and high loading conditions were each evaluated over an approximate period of five weeks. Several days were provided before each analysis period for the system to acclimate to the change in loading. Typically, this acclimation period extended over one to two weeks.

Phase 2: Steady State Operation Under Warm Temperature Conditions

An optimum system loading rate was selected based on an analysis of the data collected from Phase 1. This selection was aided by use of a computer simulation model of fixed film kinetics with particular application to the RBC system. The second phase of the program studied long-term steady state operation of the RBC at the pre-selected optimum loading rate applied during warm temperature conditions and low dissolved oxygen levels. A two-week acclimation period was provided before this study period, which lasted two months.

Phase 3: Steady State Operation Under Cold Temperature

Phase 3 of the experimental program imposed the optimum loading on the system during winter, cold temperature conditions for a period of 2-1/2 months. The loading was maintained at or near that evaluated during the summer months.

SAMPLING

Seven sampling locations were utilized to monitor water quality through the RBC system. These are shown on Figure 2. Daily, 24-hour flow-proportioned composite samples were drawn from the raw influent, RBC influent, and the final effluent from the RBC/Underflow Clarifier. Discrete samplers, ISCO model number 1680 with multiplexers, model number 1295, were positioned at the RBC influent and underflow clarifier effluent; a single composite sampler, ISCO model number 1580W, was maintained in the raw influent waste stream. Each sampler was packed with ice during sampling periods.

Periodically throughout each of the study conditons, 24-hour flow-proportioned composite samples were drawn from each of the four stages in the RBC system. These samples were drawn from mid-depth with submersible pumps, and composited in 18.9 l (5 gal) jugs. The sample jugs were kept in 67.7 l (20 gal) plastic trash cans packed with ice and insulated. All samplers were engaged by a signal from the effluent flow meter. Icing was omitted in the winter when ambient temperatures remained below freezing.

ANALYTICAL PROGRAM

Table 2 summarizes the analytical schedule followed during the major phases of the experimental program. The numbers indicate the number of samples to be analyzed per week. Thus, as an example, the raw influent total 5-day Biochemical Oxygen Demand (BOD_5) was analyzed seven times per week, or daily. During each acclimation period the analysis was limited to monitoring the RBC influent and RBC effluent for total and soluble BOD_5 and Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). These data were used to determine the extent of acclimation.

Sludge was pumped at a constant rate from the RBC clarifier sludge hoppers two to three times daily. Pumping time was measured to determine the total volume of sludge removed. During each pump cycle, a sample was taken by continuously drawing off a side stream from the sludge pump. Composite sludge samples were then constructed by combining the samples in direct proportion to the pumping volume. These composite samples were used for laboratory analysis, as indicated on Table 2.

Analysis of Total Volatile Solids (TVS) and Total Volatile Suspended Solids (TVSS) was discontinued after June 30, 1977 since the data correlated well with the Total Solids (TS) and TSS results. The frequency of analyses for the nitrogen series was reduced following the summer, warm temperature loading condition. Sulfate and total sulfide analyses were conducted only intermittently on the raw influent waste. Ortho- phosphate and total phosphate analyses were conducted occasionally, typically in conjunction with grease and oil analyses, on the raw influent, RBC influent, and RBC effluent samples.

TABLE 2. ANALYTICAL SCHEDULE
(NUMBER OF SAMPLES ANALYZED PER WEEK)

Analysis(4)	Raw influent	RBC influent	Stages 1,2,3&4	RBC effluent	RBC sludge
Flow	Recorded			Recorded	When drawn
Temperature		7		7	
pH	7	7	7	7	
DO	7	7	7	7	
BOD_5 (T)	7	7		7	
BOD_5 (S)	5	5	2(1)	5	
COD (T)	5	5		5	
COD (S)	5	4	2(1)	5	
TS					When drawn
TVS					When drawn
TSS	7	7	2(1)	7	
TVSS	7	7	2(1)	7	
TKN (T)(2)	3	3	1(1)	3	
TKN (S)(2)	3	3	2(1)	3	
NH_3-N(2)	3	3	2(1)	3	
NO_2-N(2)	3	3	2(1)	3	
NO_3-N(2)	3	3	2	3	
SO_4		1	1(1)	1	
Total sulfide(2)		1	1(1)	1	
Grease/oils (T)(3)	biweekly	biweekly		biweekly	
PO_4-P total(3)		Periodically			
PO_4-P T-ortho(3)		Periodically			

(1) Only during interstage studies.

(2) Conducted at EPA Laboratories, Cincinnati, Ohio.

(3) Conducted at the Hydroscience Laboratory, Westwood, New Jersey.

(4) (T) = Total; (S) = Soluble, as defined by filtrate.

Interstage analyses were conducted approximately twice per week during each of the major study phases. Table 2 indicates the analyses conducted on each of the stage samples.

Dissolved oxygen (DO) and temperature of sewage were measured daily on samples drawn at peak hydraulic conditions (10 to 11 AM). A YSI Model 51B with field probe was utilized. Daily pH measurements were made on the 24-hour composite samples, using an Accumet Model 150 pH Meter.

All filtrations for separation of the soluble fraction were performed immediately upon receipt of the samples. Whatman No. 2 filter papers were used throughout. Whatman 4.25 cm GF/C pads were used in the gravimetric analysis for suspended solids. Analyses for COD, TSS, and TVSS were typically performed within 24 hours of receipt of samples. Samples for BOD_5 were accumulated and set twice a week, typically on Wednesdays and Fridays. The filtrates and total samples were preserved by freezing. Special studies indicated that samples held four days (frozen) did not exhibit any significant change in BOD_5. Four days was typically the maximum time a sample was held for BOD_5 analysis.

Samples for the nitrogen series and sulfide analyses were preserved according to Standard Methods(1) and shipped via air freight to the U.S. EPA Waste Identification and Analysis Section Laboratory, Cincinnati, Ohio, for analysis. Grease and oil samples were preserved by acidification and shipped to the Hydroscience Westwood Laboratory for analysis. The samples for phosphorus analysis were frozen and also analysed at the Hydroscience Laboratory. All other analyses were conducted by Hydroscience personnel at the Edgewater Treatment Plant Laboratory. Edgewater personnel were responsible for all sampling, and the maintenance and operation tasks associated with the RBC system. Additionally, Edgewater personnel conducted flow, DO, temperature, and pH measurements as required by the schedule.

Analysis for TS, TVS, TSS, TVSS, total Kjeldahl nitrogen (TKN), ammonia (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N), sulfate (SO_4), sulfide (S-), grease and oil and phosphorus (PO_4-P) were conducted according to Standard Methods and/or U.S. EPA recommended(2) procedures.

The BOD_5 analysis was performed by a modified multiple dilution procedure as described by Standard Methods. Stale, settled raw influent was used in all cases as seed. A standard solution of 150 mg/l each of Glutamic Acid and Glucose was analyzed regularly as a routine check on technique and reagent quality. The mean BOD_5 measured for 21 samples (6 dilutions per sample) was 193 mg/l, with a standard deviation of 19 mg/l. This compares favorably with the results reported by Standard Methods.

The COD analyses were performed using a modified rapid procedure as developed by Jeris (3). Split samples were analyzed by both the rapid method and the Standard Methods reflux procedure. The results indicated no significant difference between the two procedures relative to the Edgewater waste samples. A standard solution of 0.850 mg/l potassium hydrogen phthalate, with an equivalent COD of 1,000 mg/l, was analyzed frequently as a control of procedure and reagent quality. For a total of 108 standards analyzed by the modified rapid procedure, a mean of 1,003 mg/l COD was obtained, with a standard deviation of 6.6 percent.

In addition to the water quality analyses as outlined in Table 2, studies were conducted periodically to characterize the physical and hydraulic operation of the system. These included tracer analyses, zone and flocculant settling tests, diurnal loading studies, and chemical addition tests.

During each flow condition, or major modification to the physical system, a tracer analysis was conducted to characterize the hydraulics through the RBC system and to monitor the system for any physical abnormality such as leakage, etc. Lithium chloride was evenly distributed across the RBC influent channel and samples taken with time at selected sampling locations (see Figure 2). The samples were then transported to the Hydroscience Westwood Laboratory for analysis of lithium by standard atomic absorption spectrophotometer procedures.

Flocculant settling tests were conducted using 2.13 m (7 ft) high, 15.24 cm (6 in) diameter columns with sampling ports at 0.305 m (1 ft) intervals. Sample (typically from the fourth stage) was pumped into the column and aliquots drawn at each port at regular time intervals. Standard jar test procedures were employed to evaluate the effects and feasibility of chemical addition to improve solids capture in the RBC/Underflow Clarifier.

Diurnal analyses were conducted to determine COD and SS concentration and loading variability over a 24-hour period. Discrete samplers were utilized, and a series of samples, representing specific increments of waste volume to the RBC system, were analyzed for COD and SS.

SECTION 6

EXPERIMENTAL RESULTS - SUMMARY AND ANALYSIS

INTRODUCTION

A considerable amount of monitoring data was obtained over the one-year experimental period at Edgewater. Complete tabulations of these data may be found in Appendix A. Table A-1 presents all routine monitoring data relating to flow, pH, DO, temperature, BOD_5, TSS and COD. Table A-2 summarizes all nitrogen series analyses, including interstage data. Sulfur data are contained in Table A-3, and the grease and oil, and phosphorus data are presented in Tables A-4 and A-5, respectively. All interstage data relating to BOD_5, COD, SS and DO are contained in Table A-6. For convenience and ease in the presentation and analysis of the performance of the RBC/Underflow Clarifier system, the data are presented in terms of summary tables and chronological records within the text of this report.

The system was evaluated in five periods, including a series of three loading conditions and under summer and winter operation at a prescribed optimum loading rate. Table 3 presents a summary of the performance and operation of the system during each of these periods.

HYDRAULIC CHARACTERIZATION OF THE RBC SYSTEM

Pretreatment

To preclude the accumulation of debris in the RBC system and clogging of the openings within the media, sufficient treatment of the waste to remove solids must be provided prior to the RBC system. At Edgewater, the entire plant flow passes through a detritor. Additional pretreatment provided for the RBC system influent consisted of a high rate gravity settling zone followed with coarse screening. The intake for the influent pump to the RBC system was a 0.203 m (8.0 inch) diameter pipe. Early in the study period, the intake pipe faced the direction of flow 1.52 m (5.0 ft) from the raw influent channel, and 0.76 m (2.5 ft) below the water surface. The intake in this position was too close to the influent channel and was drawing solids from the sludge hopper located directly below the channel. The resulting water quality was not suitable for application to the RBC system. Heavy solids were accumulating on the media surface, a condition which cannot be tolerated over an extended period of time.

TABLE 3. SUMMARY OF MONITORING DATA - EDGEWATER RBC/UNDERFLOW CLARIFIER SYSTEM

Parameter(1)	Low loading period 3/22/77-4/6/77	Moderate loading period 4/11/77-5/13/77	High loading period 5/23/77-6/30/77	Warm temp. period 7/18/77-9/25/77	Cold temp. period 12/1/77-2/24/78
Total plant flow m^3/d	12,870	9,000	8,360	8,515	11,355
(mgd)	(3.4)	(2.39)	(2.21)	(2.25)	(3.0)
RBC plant flow m^3/d	1,060	1,440	2,520	1,550	1,490
(mgd)	(0.28)	(0.391)	(0.665)	(0.409)	(0.393)
RBC sludge flow m^3/d	6.06	7.19	11.36	8.7	8.33
(mgd)	(0.0016)	(0.0019)	(0.0030)	(0.0023)	(0.0022)
RBC hydraulic loading $m^3/d/m^2$	0.058	0.079	0.14	0.085	0.081
(gpd/ft^2)	(1.42)	(1.94)	(3.38)	(2.08)	(2.0)
BOD_5 Raw influent (T)	90	155	144	130	154
mg/l (S)	54	96	77	87	79
RBC influent (T)	92	148	143	134	158
(S)	48	98	75	97	91
RBC effluent (T)	15	23	55	29	33
(S)	10	22	31	23	24
$TBOD_5$ Removal (%) (RBC influent to effluent)	84.1	84.3	61.5	78.7	79.0
$TBOD_5$ loading rate $g/d/m^2$	5.31	11.7	19.7	11.4	12.9
($lbs/d/1000\ ft^2$)	(1.09)	(2.39)	(4.04)	(2.33)	(2.63)
$SBOD_5$ loading rate $g/d/m^2$	2.78	7.74	10.4	8.26	7.4
(1st Stage)($lbs/d/1000\ ft^2$)	(0.57)	(1.58)	(2.13)	(1.69)	(1.52)
$TBOD_5$ loading rate $g/d/m^2$	19.4	53.4	90.1	51.9	58.9
(1st Stage)($lbs/d/1000\ ft^2$)	(4.97)	(10.9)	(18.4)	(10.6)	(12.0)
$SBOD_5$ loading rate $g/d/m^2$	10.2	35.4	47.5	37.8	33.9
(1st Stage)($lbs/d/1000\ ft^2$)	(2.6)	(7.2)	(9.7)	(7.7)	(6.9)
$TBOD_5$ removal rate $g/d/m^2$	4.47	9.86	12.1	8.95	10.2
($lbs/d/1000\ ft^2$)	(0.91)	(2.02)	(2.5)	(1.83)	(2.08)
$SBOD_5$ removal rate $g/d/m^2$	2.2	6.0	6.16	6.28	5.46
($lbs/d/1000\ ft^2$)	(0.45)	(1.23)	(1.26)	(1.38)	(1.12)
COD raw influent (T)	245	323	337	371	370
(mg/l) (S)	102	181	175	205	148
RBC Influent (T)	216	269	290	316	323
(S)	109	182	168	207	183
RBC Effluent (T)	51	78	136	118	89
(S)	46	72	95	99	77

TABLE 3. (continued)

Parameter(1)	Low loading period 3/22/77-4/6/77	Moderate loading period 4/11/77-5/13/77	High loading period 5/23/77-6/30/77	Warm temp. period 7/18/77-9/25/77	Cold temp. period 12/1/77-2/24/78
TCOD loading rate g/d/m^2	12.5	21.3	40.0	26.8	26.3
(lbs/d/1000 ft^2)	(2.57)	(4.35)	(8.2)	(5.49)	(5.39)
TCOD removal rate g/d/m^2	9.58	15.0	21.2	16.8	19.1
(lbs/d/1000 ft^2)	(1.96)	(3.08)	(4.35)	(3.44)	(3.9)
Net O_2 utilization g/d/m^2(5)	3.14	6.15	6.15	5.07	6.8
(lbs/d/1000 ft^2)	(0.64)	(1.26)	(1.26)	(1.03)	(1.4)
TSS mg/l raw influent	149	176	177	163	184
RBC influent	124	122	128	121	133
RBC effluent	24	23	57	31	24
RBC sludge	19,400	22,600	24,300	24,600	21,300
TSS removal (%) (RBC influent to effluent)	80	81	55	75	82
Nitrogen series (mg/l as N)					
raw influent TKN (T)	19.8(2)	28.4	27.8	24.2	21.2
(S)	17.7(2)	23.8	17.9	20.3	26.5(2)
NH_3-N	13.0(2)	13.3	15.3	14.9	10.1
NO_3-N	0.1(2)	<0.1(4)	0.2	<0.1(2)	-
NO_2-N	<0.1(2)	<0.1	<0.1	<0.1(2)	-
RBC influent TKN (T)	19.7	25.3	22.4	24.5	20.7
(S)	15.4	23.6	19.6	20.2	15.9
NH_3-N	10.7	13.8	15.9	14.8	7.7
NO_3-N	0.9	1.0	<0.1	<0.1	1.0
NO_2-N	<0.1	0.1	<0.1	<0.1	<0.1
RBC effluent TKN (T)	10.9	15.6	20.3	17.9	13.4
(S)	10.3	15.7	16.1	14.6	12.2
NH_3-N	9.8	12.7	14.3	11.9	9.1
NO_3-N	<0.1-3.3	<0.1-2.1	<0.1	<0.1-1.5	0.8
NO_2-N	<0.1	<0.1	0.1	0.1	0.1
Sulfur raw influent sulfide	-	<0.1(2)	<0.1	-	<0.1
mg/l sulfate	-	90	73.3	-	67.3
RBC influent sulfide	<0.1(3)	<0.1(2)	<0.1	<0.1	<0.1
sulfate	78.6(3)	86.4	89.0	84.0	71.8
RBC effluent sulfide	<0.1(3)	<0.1	<0.1	<0.1	<0.1
sulfate	78.0(3)	76.0	83.6	93.3	70.0

TABLE 3. (continued)

Parameter(1)	Low loading period 3/22/77-4/6/77	Moderate loading period 4/11/77-5/13/77	High loading period 5/23/77-6/30/77	Warm temp. period 7/18/77-9/25/77	Cold temp. period 12/1/77-2/24/78
Temperature (C) RBC effluent	13.0	17.2	23.2	26.1	11.3
Dissolved oxygen, mg/1					
RBC influent	6.9	5.0	2.2	1.55	6.1
RBC effluent	4.3	1.5	0.75	0.5	3.4
pH - RBC influent	7.2	7.2	7.3	7.1	7.4
RBC effluent	7.2	7.3	7.4	7.1	7.3

(1) All rate calculations based on effective (wetted) surface area of 18,270 m^2 (196,500 ft^2).

(2) Based on two analyses.

(3) Single analysis.

(4) One analysis at 9.8 mg/1.

(5) Based on O_2 balance presented in Figure 30.

The pipe was repositioned against the direction of flow from the primary settling tank, 3.51 m (11.5 ft) from the raw influent channel. The resulting settling area was sufficient to provide adequate grit and trash removal while allowing most primary solids to enter the system. With the intake positioned well below the water surface, intake of floatables (grease and oils) was minimized.

Figure 6 presents the approximate overflow rate in the high rate primary sedimentation section as a function of both plant flow and flow directed to the RBC system. The total flow passing thru this portion of the tank is the sum of the Tank 3 effluent (see Figure 2) and the pumped flow. The pumped flow is split between Tank 4 and the RBC system. Thus the computed overflow rate is dependent upon both the total plant flow and the RBC flow. The nominal surface area used in the computation assumes use of the entire area to the point of intake, i.e. 4.27 m (14.0 ft) wide by 3.51 m (11.5 ft) long, or 15 m^2 (160 ft^2). This is conservative, since the effective surface may be considerably smaller due to the constricted influent to the tank and the constructed intake. The shaded area on the figure presents the normal operating range for the RBC unit, indicating high rate primary treatment overflow rates between 285 and 370 $m^3/day/m^2$ (7,000 and 9,000 gpd/ft^2).

RBC/Underflow Clarifier

Seven tracer studies were conducted and analyzed during the experimental program. Lithium was batch loaded into the RBC influent channel and sampled at selected points through the system. The data analysis was directed to defining effective detention times in key portions of the system and to monitor the system for any apparent occurrence of short-circuiting or other physical anomalies such as leakage. The initial study, conducted November 2 through 5, 1976, determined that there was significant leakage through the intermediate floor, and poor distribution at the influent channel. These problems were corrected as part of the plant modifications program conducted December 1976 through February 1977, as described in Section 4. The tracer studies conducted during March through October 1977 showed no recurrence of these problems.

Subsequent tracer studies conducted on the Edgewater RBC/Underflow Clarifier system were under the following operating modes:

March 2: $Q = 2000\ m^3/d$ (0.525 mgd), baffles between shafts 2 and 3, and 3 and 4.

March 25: $Q = 1200\ m^3/d$ (0.32 mgd), baffles between shafts 1 and 2, 2 and 3, and 3 and 4.

May 24: $Q = 3000\ m^3/d$ (0.8 mgd), baffles between shafts 1 and 2, 2 and 3, and 3 and 4.

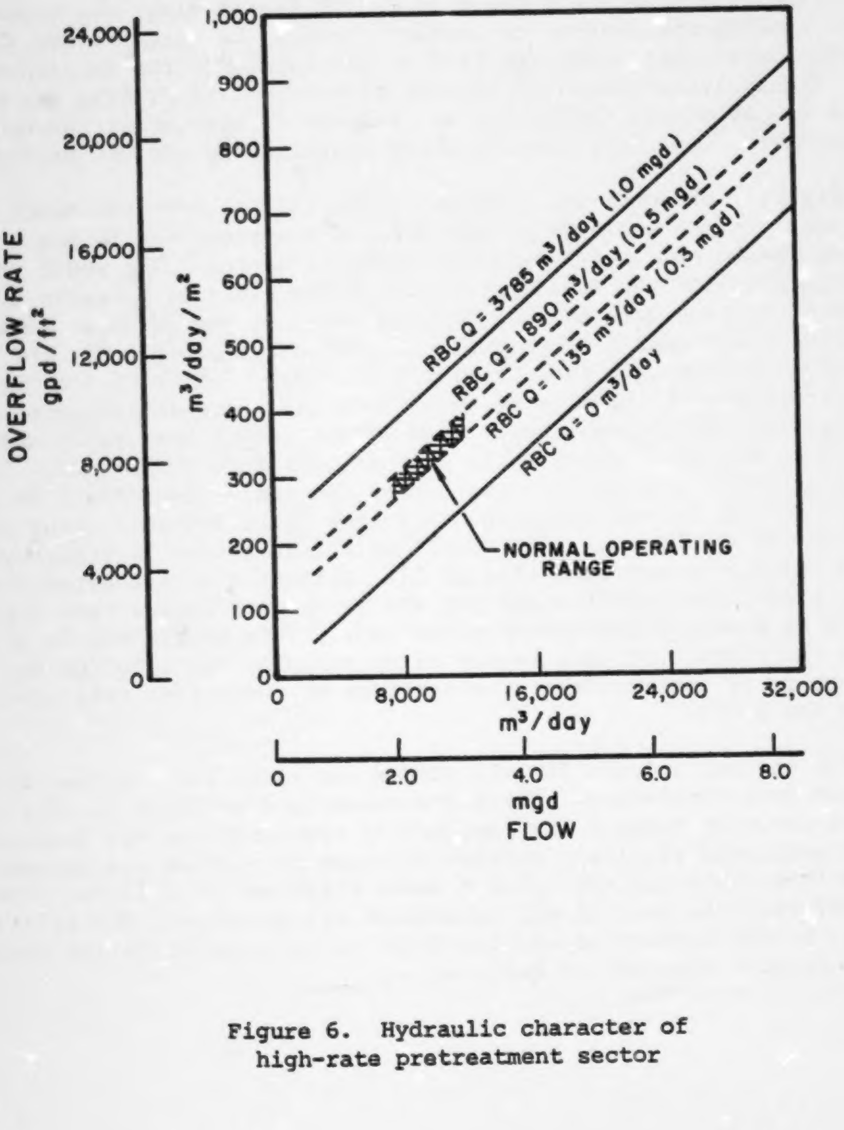


Figure 6. Hydraulic character of high-rate pretreatment sector

June 23: Q = 3000 m^3/d (0.8 mgd), baffles between shafts 2 and 3, 3 and 4, and after shaft 4.

Oct. 3: Q = 1900 m^3/d (0.50 mgd), baffles between shafts 1 and 2, 2 and 3, 3 and 4 and after shaft 4.

A seventh tracer study was conducted on July 14 to determine if back dispersion from the turnaround to the fourth stage was occurring, and to confirm the absence of leakage through the intermediate floor. For this particular study the lithium was loaded in the turnaround sector. The analysis indicated no back dispersion and lithium was not detected in any stage, confirming no exchange of wastewater through the intermediate floor from the underflow clarifier to the RBC sector.

Figure 7 presents the lithium tracer results from the March 2, 1977 run. In the analysis of the data, a non-steady-state model was applied, based on completely mixed tanks in series. The model used was a modification of the steady-state model described in Appendix B. Non-steady conditions were imposed in this case and the influent substrate constituent was assumed conservative. The solution includes the diffusivity of lithium into (and from) the biofilm. Initially the higher concentration of lithium is in the liquor and there is diffusion into the biofilm. With time, the lithium washes out of the system and the lithium in the biofilm begins to diffuse back into the liquor. The overall effect is to cause a tailout of the tracer and affect an apparently longer liquid detention time than would actually occur under steady-state conditions. The result of this solution is superimposed on the March 2 survey data (Figure 7). Without a baffle after the fourth shaft, the fourth stage and the turnaround sector (see Figure 4) behaved as a single completely mixed tank. This single run is provided within the context of this report as an example; the solution was determined to be applicable to the spectrum of conditions evaluated during the study.

The nominal volumes for all stages and zones are computed directly from the tank dimensions. These are summarized on Table 4. The actual volumes shown on Table 4 are computed by approximating the displacement of the media and biofilm. A film thickness of 0.23 cm was assumed for use in these calculations, with a media thickness of 0.15 cm. The actual volumes were used in all subsequent calculations. The effective volumes of the turnaround and clarifier sectors are different than the actual volumes reported in Table 4.

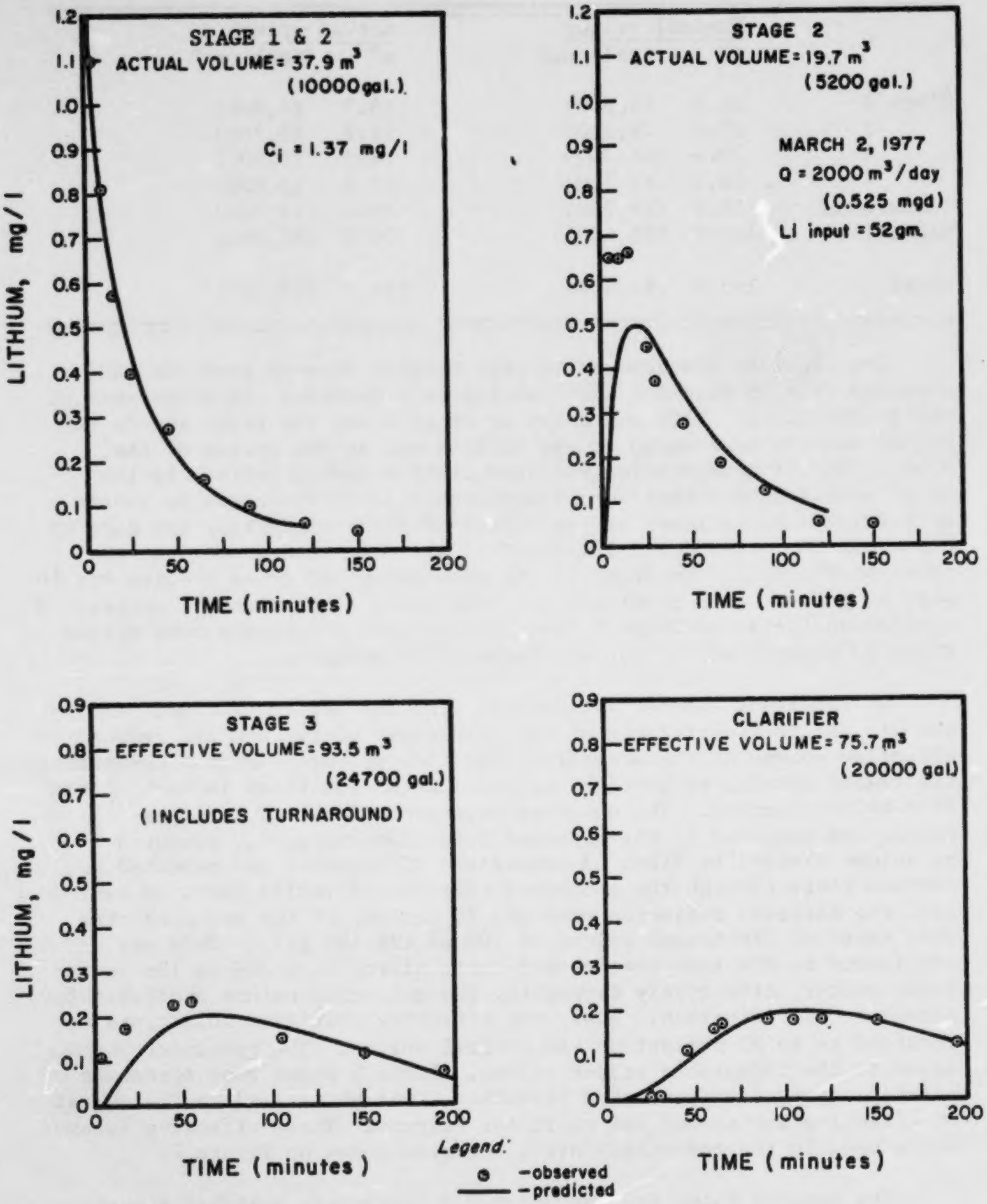


Figure 7. Results of March 2nd hydraulic tracer analysis

TABLE 4. RBC/UNDERFLOW CLARIFIER - NOMINAL AND ACTUAL VOLUMES

	Nominal volume		Actual volume	
	m^3	(gallons)	m^3	(gallons)
Stage 1	21.9	(5,800)	18.2	(4,800)
2	23.5	(6,200)	19.7	(5,200)
3	23.5	(6,200)	19.7	(5,200)
4	19.3	(5,100)	13.6	(3,600)
Turnaround	55.6	(14,700)	55.6	(14,700)
Clarifier	100.0	(26,400)	100.0	(26,400)
Total	243.8	(64,400)	226.7	(59,900)

The apparent discrepancy in peak heights between predicted and observed data in Stages 2 and 3 on Figure 7 suggests the occurrence of short-circuiting. This was known to occur along the floor due to the higher velocities created at the baffles and at the bottom of the discs. The lithium studies measured lithium concentrations in the later stages sooner than should have occurred if there was no short-circuiting. An estimate of the degree of short-circuiting was made by comparing the areas under the observed and predicted tracer curves shown on Figure 7. In Stage 2, the mass passed after 25 minutes was 10 percent greater than predicted for completely mixed tanks in series. A similar analysis for Stage 3 (plus turnaround) showed the mass passed after 50 minutes was 11 percent higher than predicted.

An important observation derived from the series of tracer analyses was the ineffective use of the turnaround sector and the reduced effective volume of the underflow clarifier sector. Table 5 summarizes the tracer results as given by measured detention times in each of the five tracer studies. The observed detention times, t_m, are presented and compared to the expected detention times, t_o, computed as volume divided by flow. A comparison of observed and expected detention times through the secondary clarifier revealed that, on average, the observed detention time was 75 percent of the expected time when based on the actual volume of 100 m^3 (26,400 gal). This was attributed to the fact that considerable mixing occurred in the turnaround sector, effectively decreasing the quiescent volume available for secondary clarification. Thus, the effective clarifier volume was determined to be 75 percent of the nominal volume. The remainder was added to the turnaround sector volume. Table 5 shows good agreement between observed and expected detention times when based on the adjusted effective turnaround and clarifier volumes. These effective volumes where used in the non-steady state solution shown on Figure 7.

The results shown for the October 3 survey are somewhat anomalous relative to the previous studies, whereby the measured detention time in the Stage 4 and turnaround sectors are lower than the expected detention time. No conclusive reasons are evident. Recovery during the

TABLE 5. EFFECTIVE CLARIFIER VOLUME ANALYSIS

	% Li Recovery	Actual			Effective		
		Shaft 4	Turnaround	Clarifier	Shaft 4	Turnaround	Clarifier
Actual volume, m3		19.3	55.6	100.0			
Effective volume, m3					19.3	80.6	75.0
Tracer study (1)							
3/2/77; Q = 1990 m^3/day	106	combined			combined		
t_o		50.2		72.4	67.8		54.9
t_m		77.9		53.1	77.9		53.1
3/24/77; Q = 1210 m^3/day	92	combined			combined		
t_o		82.4		119.0	111.0		90.0
t_m		128.0		83.5 (70%)	128.0		83.5
5/24/77; Q = 3030 m^3/day	83	combined			combined		
t_o		32.9		47.5	44.5		36.0
t_m		41.0		33.1 (70%)	41.9		33.1
6/23/77; Q = 2975 m^3/day	83						
t_o		6.6	26.9	48.4	6.6	38.7	36.6
t_m		17.7	31.4	36.3 (75%)	17.7	31.4	36.3
10/3/77; Q = 1890 m^3/day	70						
t_o		10.4	42.3	76.0	10.4	60.8	57.6
t_m		6.3	29.8	65.6 (86%)	6.3	29.8	65.6

(1) t_o = V/Q; t_m = observed detention time (minutes).

study was poor (70 percent). It is suggested that the lower flow rate (1,890 m^3/d vs. 2,975 m^3/d during the June 23 survey, conducted under a similar operation mode) may have effectively created a dead zone in the turnaround sector. The lower velocities would have caused less mixing and a more direct routing to the underflow clarifier zone.

In summary, the following observations were made from the tracer analyses conducted during the experimental program:

(1) Each stage in the RBC sector with either one or two shafts, as defined by baffle placement, behaves closely as a completely mixed tank.

(2) The combined turnaround and fourth shaft sectors, without the baffle separation, behave as a completely mixed tank.

(3) Short-circuiting is apparent in the RBC sector, probably due to the higher velocities created at the baffles along the intermediate floor. It is felt that the degree to which it occurs is minor. Removal and kinetic coefficients determined in this study would, of course, reflect any short-circuiting which may occur through the system.

(4) The effective volume of the clarifier was estimated to be 75 percent of the actual volume, the remainder of which is part of the completely mixed turnaround sector.

WASTE CHARACTERIZATION

Raw Wastewater

The Edgewater sewerage system is a combined sanitary/stormwater collection system. Wastewaters received are predominantly domestic with approximately a 7 percent input from industrial sources. As a combined system, periods of rain result in a dilution of the waste strength to the system. Table 6 summarizes the monthly waste characterization for both the plant raw influent and the RBC influent. The plant raw influent is representative of samples drawn from the influent channel to the primary tanks, subsequent to the detritor. The RBC influent samples were drawn from the distribution channel prior to shaft one.

Weekly average plant raw influent waste characteristics are chronologically displayed on Figure 8. Included on the figure are the precipitation record and the flow to the RBC unit. Periods of rain reduce the waste strength considerably, as evidenced during generally wet and dry seasons and with occasional storms. Since the flow to the RBC was maintained at a fixed daily average flow and diurnal pattern, the storm periods with high dilutions and flows were experienced by the RBC only at lower waste loading periods. Conversely, during periods with low

TABLE 6. MONTHLY TOTAL PLANT AND RBC PLANT INFLUENT WASTEWATER CHARACTERIZATION SUMMARY, EDGEWATER, NEW JERSEY - MARCH 1977 TO FEBRUARY 1978

	Raw Influent				RBC Influent							
	Flow		TBOD$_5$	TCOD	TSS	Flow		TBOD5	SBOD5	TCOD	SCOD	TSS
	m /d	(mgd)	mg/1	mg/1	mg/1	m /d	mgd	mg/1	mg/1	mg/1	mg/1	mg/1
1977												
March	11695	(3.09)	105	263	169	1280	(.338)	107	60	252	127	137
April	10105	(2.67)	136	298	164	1420	(.375)	135	90	263	167	118
May	8474	(2.24)	146	338	175	1858	(.491)	142	84	271	170	120
June	8554	(2.26)	144	338	178	2615	(.691)	145	78	298	175	130
July	7910	(2.09)	162	330	183	1843	(.487)	138	88	291	185	125
August	8516	(2.25)	125	353	180	1480	(.391)	127	91	302	199	118
Sept.	8894	(2.35)	141	407	146	1525	(.403)	151	128	346	223	117
Oct.	10636	(2.81)	159	326	122	1872	(.495)	154	99	313	201	112
Nov.	11166	(2.95)	145	393	161	2090	(.552)	133	97	287	194	119
Dec.	12148	(3.21)	125	320	121	1491	(.394)	145	78	317	168	180
1978												
January	11431	(3.02)	136	319	170	1404	(.371)	139	89	268	159	116
February	10295	(2.72)	194	467	243	1590	(.420)	191	102	395	223	158

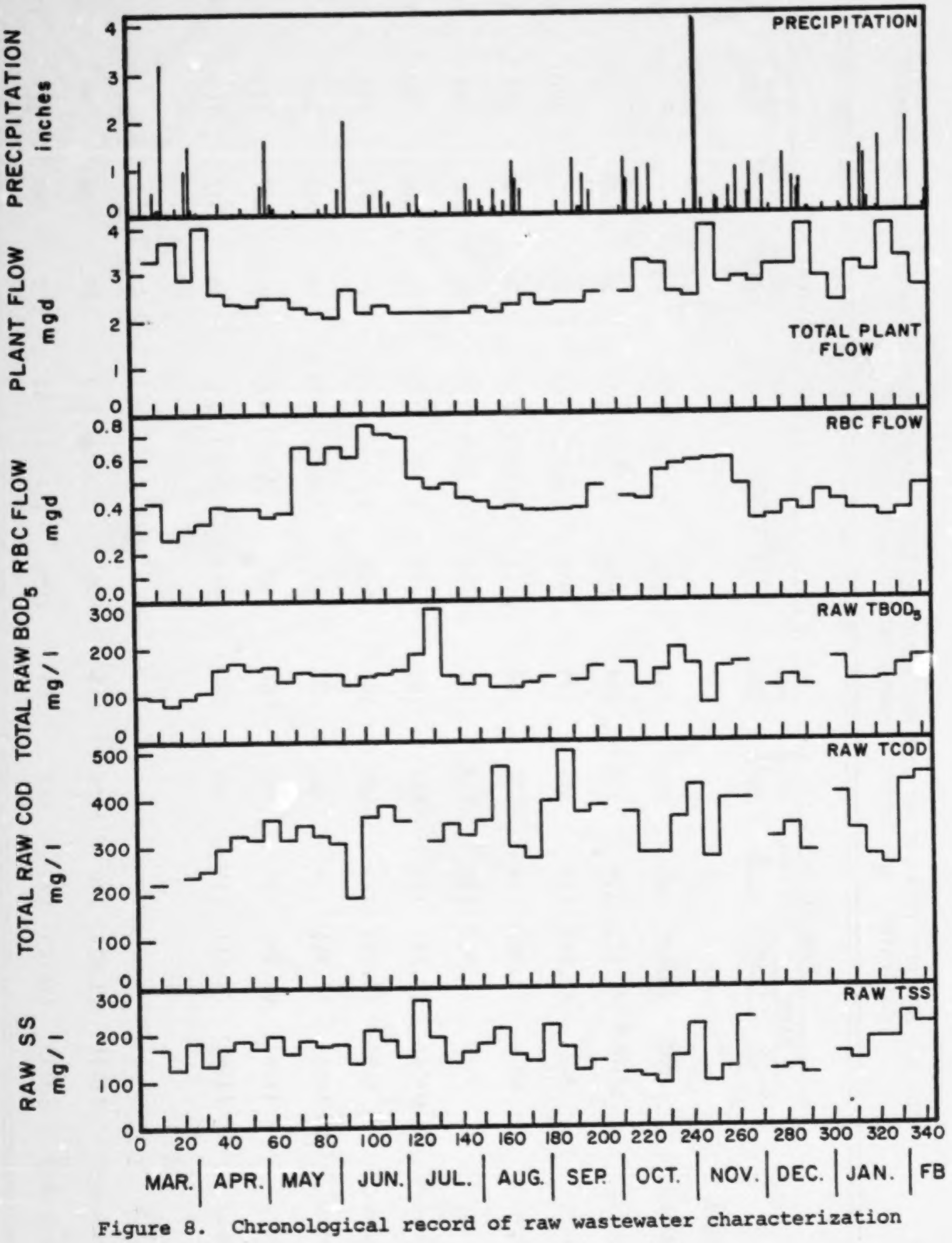


Figure 8. Chronological record of raw wastewater characterization

plant flows and resulting higher-strength wastes, the RBC system received an increased waste load.

Diurnal Variations

Diurnal sampling was conducted twice on the raw influent, RBC influent, and RBC effluent waste streams to characterize the variations occuring over a 24-hour period. Throughout the experimental program the RBC flow was controlled at a fixed diurnal pattern, as shown on Figure 5. The expected peak-to-average and minimum-to-average flow ratios were 1.5 to 1.0 and 0.5 to 1.0, respectively. These flow ratios are consistent with the diurnal flow variations generally experienced at the Edgewater STP. The maximum-to-average and minimum-to-average flow ratios actually realized during the June and October diurnal samplings were as follows:

	June 8-9	October 5-6
Maximum/Average Ratio	1.53	1.63
Minimum/Average Ratio	0.42	0.44

The average RBC flows for the June and October diurnal studies were 2,710 m^3/d (0.71 mgd) and 1,360 m^3/d (0.36 mgd), respectively.

The diurnal variations of pollutant concentrations tended to lag the diurnal waste flow pattern, thereby resulting in greater diurnal variations in waste loading than occur with the flow.

Figure 9 displays the results of the June 8-9, 1977 diurnal sampling, presenting the variations in flow, COD, and TSS. The results obtained during the October analysis showed similar responses. During both studies the peak influent organic loading occurred between 9 and 11 AM, when the hydraulic loading was maximum. The effluent mass discharge is shown to display the same variations to the influent mass loading. The maximum-to-average and minimum-to-average ratios derived from both the June and October diurnal studies are as follows:

	Influent	
	TCOD	TSS
Maximum/Average	1.69	2.0
Minimum/Average	0.44	0.25

The diurnal variation of the RBC fourth stage dissolved oxygen concentration is displayed on Figure 10. The 24-hour oxygen profile, recorded 10/4-5/77, shows marked diurnal variations consistent with the waste load variation imposed on the RBC system. All DO monitoring data reported herein represent levels between 9 and 11 AM; as shown on Figure 10, these are actually the minimum DO levels experienced by the system through the day.

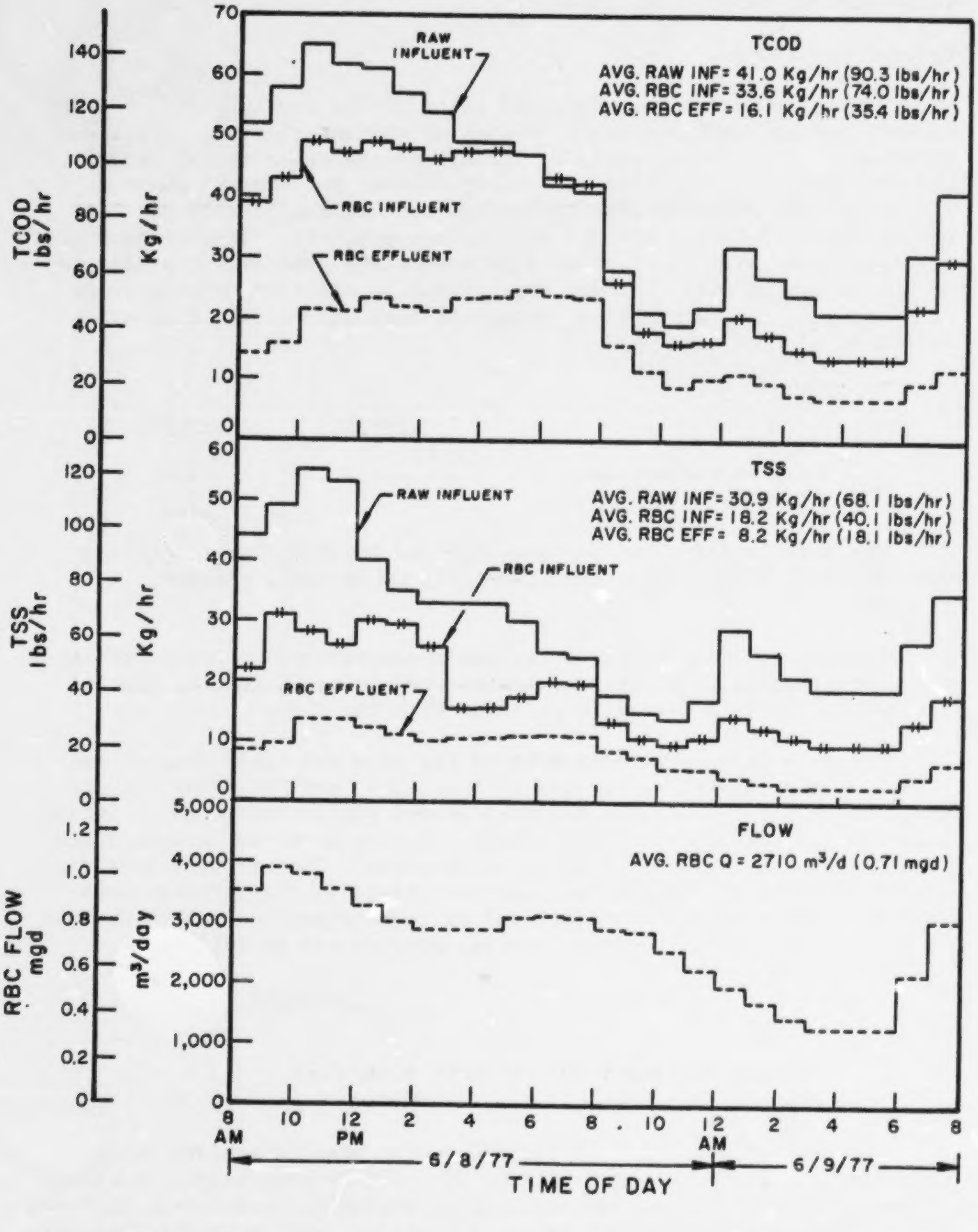


Figure 9. Diurnal variations of TCOD, TSS, and RBC flow

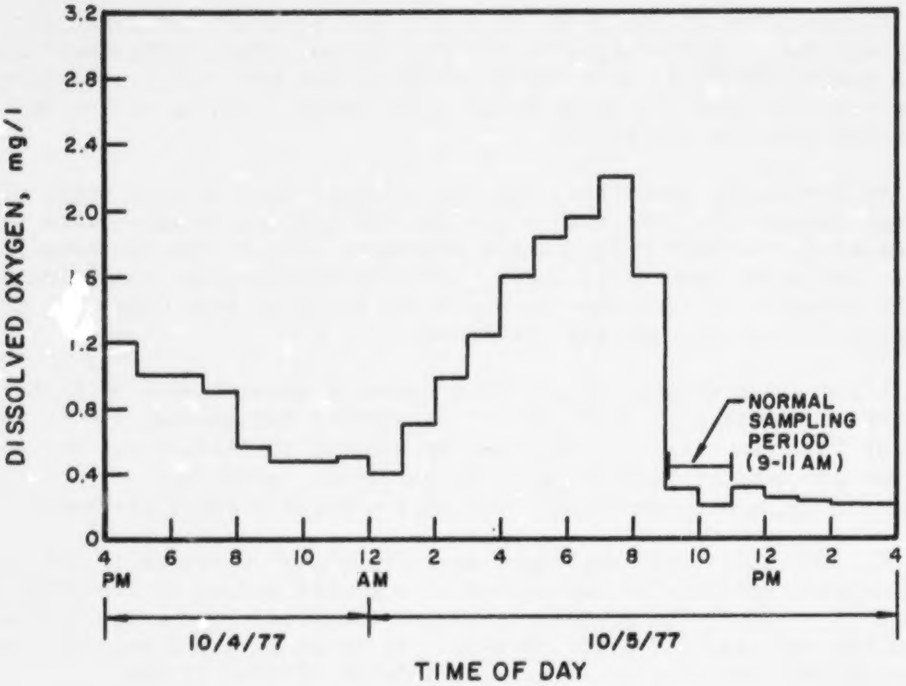


Figure 10. Example of diurnal dissolved oxygen variations

Parameter Correlations

Correlations between major water quality parameters were developed and are summarized on Table 7. These relationships reflect changes in waste characteristics with the various levels of treatment in the RBC system.

PRETREATMENT

Pretreatment of the waste to remove heavy solids and trash was necessary before application to the RBC system. The pretreatment provided removal of grit, scum and floatables, and the heavier fraction of primary solids from the waste which could cause clogging of the media if passed into the RBC system.

As previously described, the raw influent samples were taken after passage through the detritor, while the RBC influent samples were obtained after the high rate primary treatment zone at the RBC pump intake. The waste reductions accomplished by pretreatment described removals obtained in this high rate primary settling zone only. Refer to Figure 2 for actual sampling locations.

Figure 11 presents TSS and TCOD removals accomplished by high rate primary treatment. As shown, 20 to 25 percent TSS removal and 10 to 15 percent TCOD removals were observed at nominal overflow rates between 280 and 370 $m^3/d/m^2$ (7,000 and 9,000 gpd/ft^2). Minor removals of $TBOD_5$ were measured, typically between 0 and 5 percent.

Periodically, settling tests were conducted to determine the settling characteristics of the solids at specific points in the process. Figure 12 presents the results of a test conducted in the raw influent which had an initial TSS of 173 mg/l. Although data was not recorded at equivalent overflow rates greater than 80 $m^3/d/m^2$ (2,000 gpd/ft^2) the results imply that TSS removals in the order of 20 percent can be expected at overflow rates between 280 and 370 $m^3/d/m^2$ (7,000-9,000 gpd/ft^2). This is similar to the results presented on Figure 11.

RBC/UNDERFLOW CLARIFIER PERFORMANCE SUMMARY

Phase I: Loading Evaluation - March through June 1977

Figures 13 through 15 present chronological records of waste loadings and reductions obtained during this phase of the study. Various loadings were applied to the RBC system to assess the optimum loading that would meet EPA effluent standards. Computed averages are shown on each of the Figures. Table 3 presents average summaries of each of the parameters analyzed during this period.

During March the flow to the RBC system was constant and did not reflect diurnal variations. The programming valve which was to accomplish this was delayed in shipment and was not installed until the

TABLE 7. CORRELATION OF MAJOR WATER QUALITY PARAMETERS

Raw influent	$BOD_5\ (T) = 0.5\ COD\ (T) - 30$
	$BOD_5\ (S) = 0.6\ COD\ (F) - 15$
	$BOD_5\ (TSS) = 0.4\ TSS - 20$
	$COD\ (TSS) = 1.0\ TSS - 30$
Raw influent	$BOD_5\ (T) = 0.6\ COD\ (T) - 20$
	$BOD_5\ (S) = 0.6\ COD\ (F) - 15$
	$BOD_5\ (TSS) = 0.5\ TSS - 20$
	$COD\ (TSS) = 1.0\ TSS - 20$
	$VSS = 0.8\ TSS$
Stage 1	$BOD_5\ (S) = 0.6\ COD\ (F) - 15$
2	$BOD_5\ (S) = 0.6\ COD\ (F) - 10$
3	$BOD_5\ (S) = 0.4\ COD\ (F) - 5$
4	$BOD_5\ (S) = 0.4\ COD\ (F) - 5$
Effluent	$BOD_5\ (T) = 0.45\ COD\ (T) - 10$
	$BOD_5\ (S) = 0.35\ COD\ (F) - 5$
	$BOD_5\ (TSS) = 0.5\ TSS - 5$
	$COD\ (TSS) = 1.0\ TSS - 10$
	$TVSS = 0.9\ TSS$
RBC sludge	$TVSS = 0.8\ TSS$

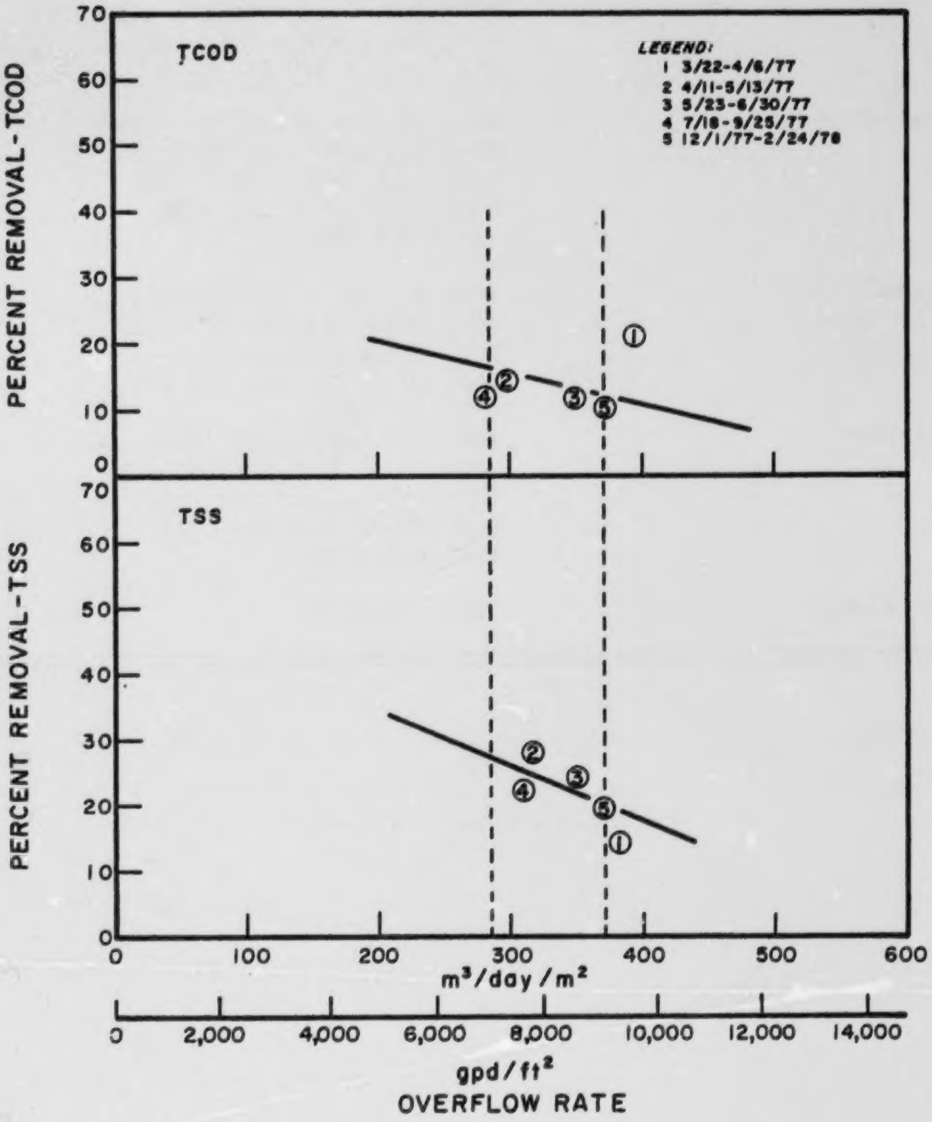


Figure 11. Performance summary of high-rate pretreatment sector

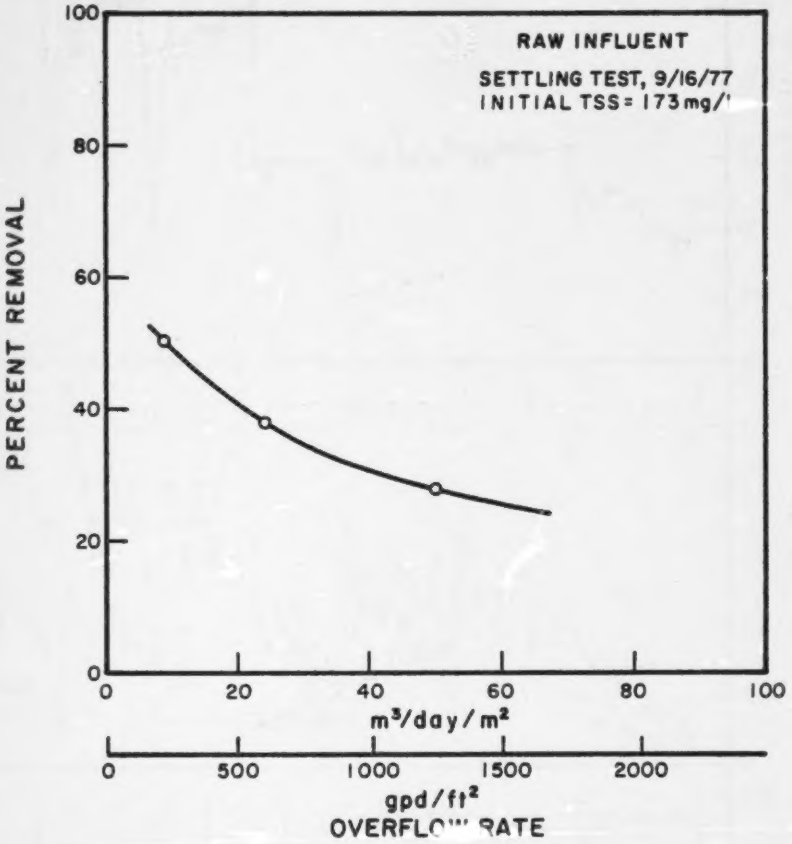


Figure 12. Settling test results on raw influent sample

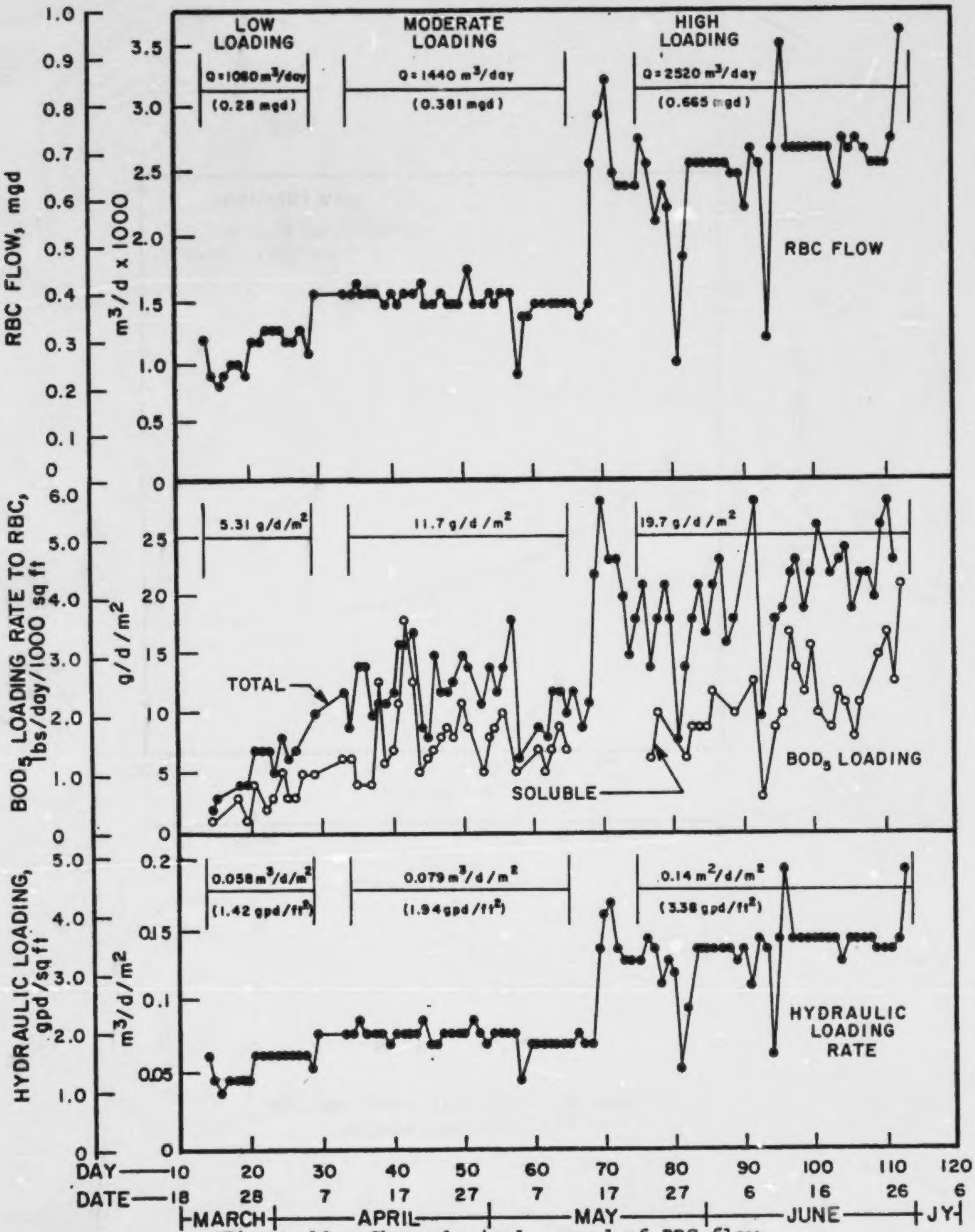


Figure 13. Chronological record of RBC flow, BOD_5 and hydraulic rates; Phase I (3/77-6/77)

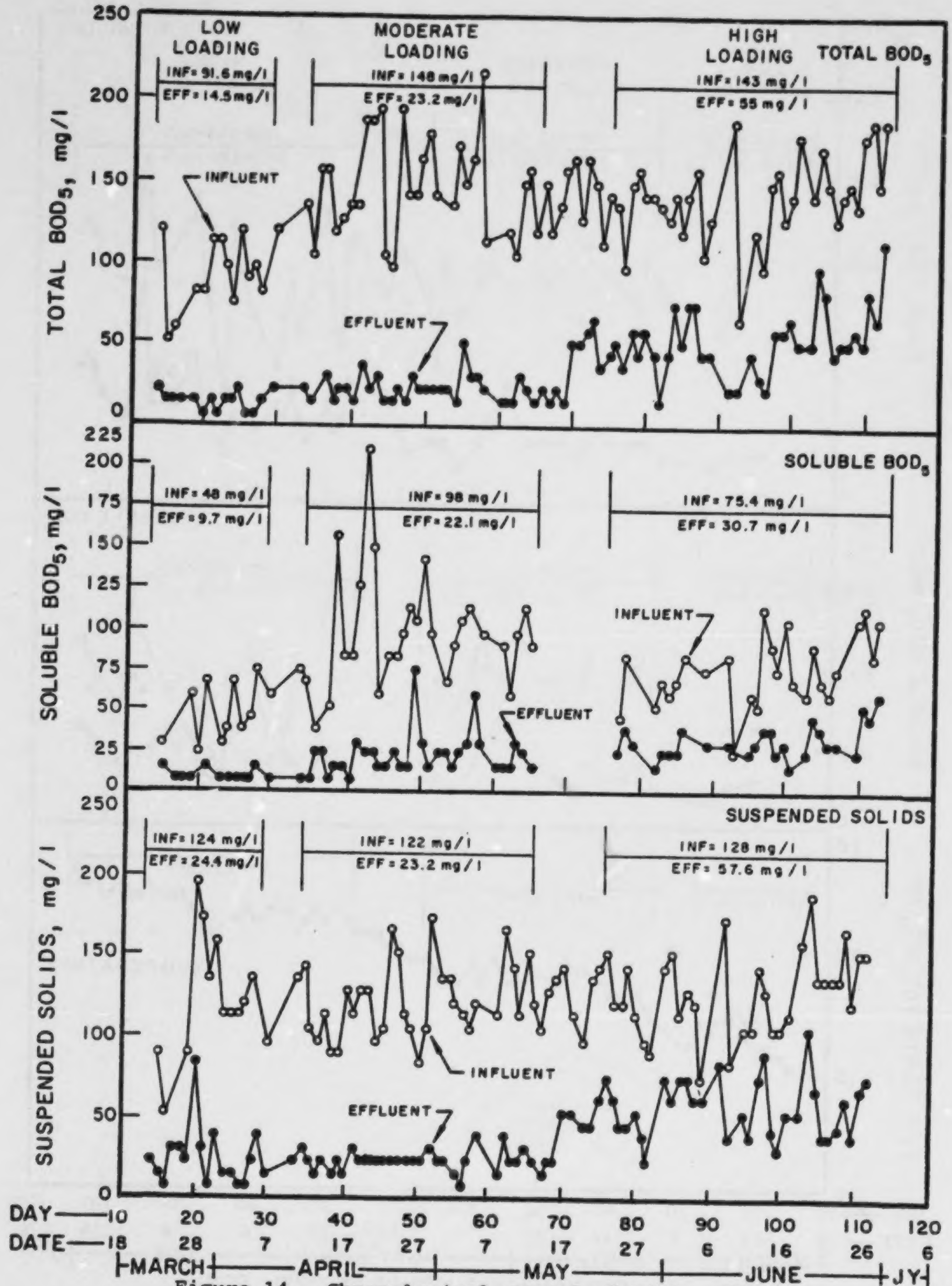


Figure 14. Chronological record of TBOD$_5$, SBOD$_5$, and TSS; Phase I (3/77-6/77)

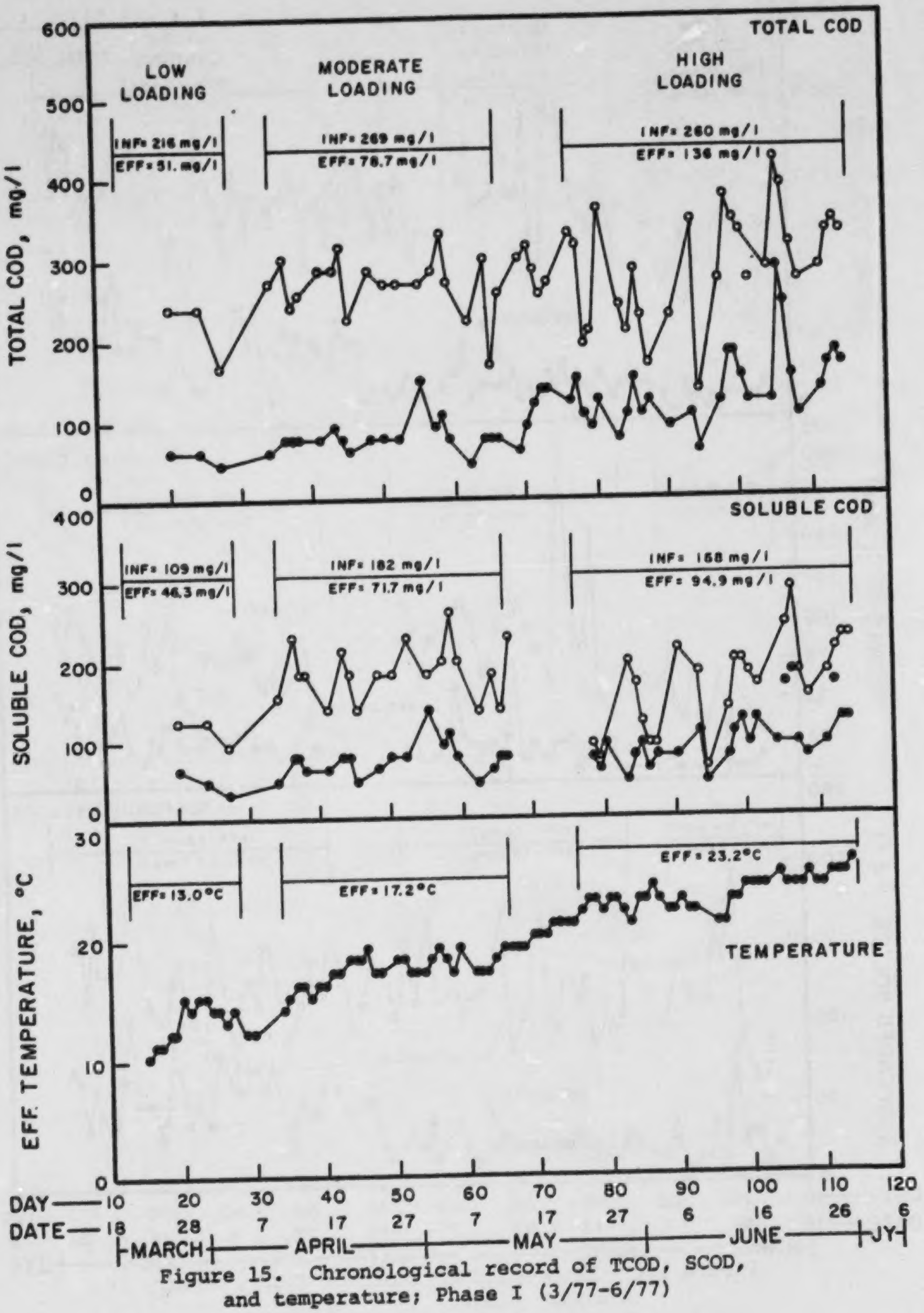


Figure 15. Chronological record of TCOD, SCOD, and temperature; Phase I (3/77-6/77)

first week of April. Thus the low loading condition was evaluated under a constant flow mode. In mid-March, deposits of solids were noted on the intermediate floor in the early stages, and were also accumulating on the media surface. To alleviate a potential problem due to solids accumulation, a baffle between Shafts 1 and 2 was installed (to increase velocity between shafts), and the influent pump intake was moved further downstream from the raw influent channel. On April 12th, the roughing screens were placed in the RBC influent channel to catch larger fibrous solids which did not settle out in the initial pretreatment step.

The low loading condition was maintained from March 22 through April 6, 1977. The RBC flow was initially set at an average rate of 760 m^3/d (0.20 mgd). This was maintained until March 29 when flows were increased to 1,140 m^3/d (0.30 mgd). The increased flow was required to maintain the desired organic loading at the low BOD_5 concentrations in the plant influent. Overall, the flow averaged 1,060 m^3/d (0.28 mgd) and was maintained for the duration of the low loading condition. The $TBOD_5$ averaged 92 mg/l and the TSS 124 mg/l, indicating a relatively dilute waste during this period. The average $TBOD_5$ loading was 5.31 g $TBOD_5/d/m^2$ (1.09 lbs $TBOD_5/d/1{,}000\ ft^2$). The BOD_5 removal rate averaged 4.47 g $TBOD_5/d/m^2$ (1.91 lbs $TBOD_5/d/1{,}000\ ft^2$) and the average effluent $TBOD_5$ was 14 mg/l. Effluent solids averaged 24 mg/l. These represented 84 percent and 80 percent BOD_5 and SS removal, respectively. The dissolved oxygen levels were relatively high throughout this time period, averaging 6.9 and 4.3 mg/l in the influent and effluent, respectively. The average temperature was 13 degrees C.

Waste reductions obtained during this loading condtion were used to aid in the selection of the flow required for the moderate loading condition, where effluents would be commensurate with EPA standards.

Diurnal flow variation was instituted on April 7 and the flow rate increased to deliver 1,510 m^3/d (0.40 mgd). This flow was maintained throughout the moderate loading study period. After approximately one week acclimation (April 6 to April 11), the moderate flow condition was investigated from April 11 through May 13, 1977. Overall, the flow averaged 1,440 m^3/d (0.38 mgd), representing an effective hydraulic loading of 0.079 $m^3/d/m^2$ (1.94 gpd/ft^2). The influent $TBOD_5$ and TSS concentrations were 148 mg/l and 122 mg/l, respectively. The $TBOD_5$ loading averaged 11.7 g $TBOD_5/d/m^2$ (2.39 lbs $TBOD_5/d/1{,}000\ ft^2$), and the resulting average effluent $TBOD_5$ was 23 mg/l (84 percent removal). This reflected a removal rate of 9.86 g $TBOD_5/d/m^2$ (2.02 lbs $TBOD_5/d/1{,}000\ ft^2$). The plant flow was relatively constant during this period resulting in uniform daily waste loadings throughout. DO concentration levels at peak diurnal loading averaged 5.0 mg/l influent and 1.5 mg/l in the effluent. The average temperature was 17.2 degrees C. Effluent TSS averaged 23 mg/l during this period (81 percent removal).

The hydraulic loading was increased on May 15 for evaluation of the system under a high loading condition. After one week acclimation the high loading was investigated from May 23 to June 30. The initial average flow setting was 2,500 m^3/d (0.66 mgd) and the organic loading was 20.0 g $TBOD_5/d/m^2$ (4.9 lbs $TBOD_5/d/1,000$ ft^2). Soon after adjustment to this new loading, filamentous bacteria appeared on all stages, most heavily on the initial stages. No steps were taken to remove them and by June 6, all signs of these bacteria were gone. They had been visually identified as the sulfur bacteria, beggiatoa, which are white-to-clear, filamentous organisms, and form large white patches on the surface of the biofilm. There was no measurable deleterious impact on treatment efficiencies during the presence of these organisms.

Tracer analyses (discussed earlier in Section 6) which were conducted to hydraulically characterize the RBC/Underflow Clarifier system, indicated that the combined fourth stage and turaround sector behaved as a single completely mixed tank. To offset this and potentially make better use of the turnaround sector for clarification, a fourth stage baffle was installed on June 10. This remained for the duration of the program. On June 21, the baffle between Stages 1 and 2 was removed to reduce the load to the first stage by doubling the available surface area in Stage 1. This was done as a precaution against excessive growth accumulations in the first shaft under the high organic loading conditions. Subsequent tracer analyses indicated that with this baffle removed, the two-shaft stage was still completely mixed. No measurable differences in treatment efficiency were observed subsequent to these modifications.

The high loading condition, conducted May 23 and June 30, was set to stress the RBC system. Overall, the flow averaged 2,520 m^3/d (0.665 mgd) which represented a hydraulic rate of 0.14 $m^3/d/m^2$ (3.38 gpd/ft^2). The influent $TBOD_5$ and TSS concentrations averaged 143 and 128 mg/l, respectively. The $TBOD_5$ loading rate averaged 19.7 $g/d/m^2$ (4.04 $lb/d/1,000\ ft^2$), resulting in an effluent $TBOD_5$ of 55 mg/l (62 percent removal). As the loading rate increased, the BOD_5 removal rate also increased. However, the percent removal of total BOD_5 through the system decreased. The average effluent TSS was 58 mg/l (55 percent removal). The increased temperatures, averaging 23.2 degrees C in this time period resulted in lower dissolved oxygen levels throughout the RBC system. The average influent DO at peak diurnal loading was 2.2 mg/l, while the effluent averaged 0.8 mg/l.

Figure 16 presents a summary of the effluent quality obtained under the various hydraulic and organic loading conditions evaluated during Phase I. As indicated, the criteria of 30 mg/l $TBOD_5$ and TSS (30-day average) would be met at hydraulic loadings between 0.08 and 0.09 $m^3/d/m^2$ (2.0 and 2.2 gpd/ft 2) and organic loadings between 12 and 14 g $TBOD_5/d/m^2$ (2.45 and 2.36 lb $TBOD_5/d/$ $1,000\ ft^2$). Based on these findings, these conditions were recom-

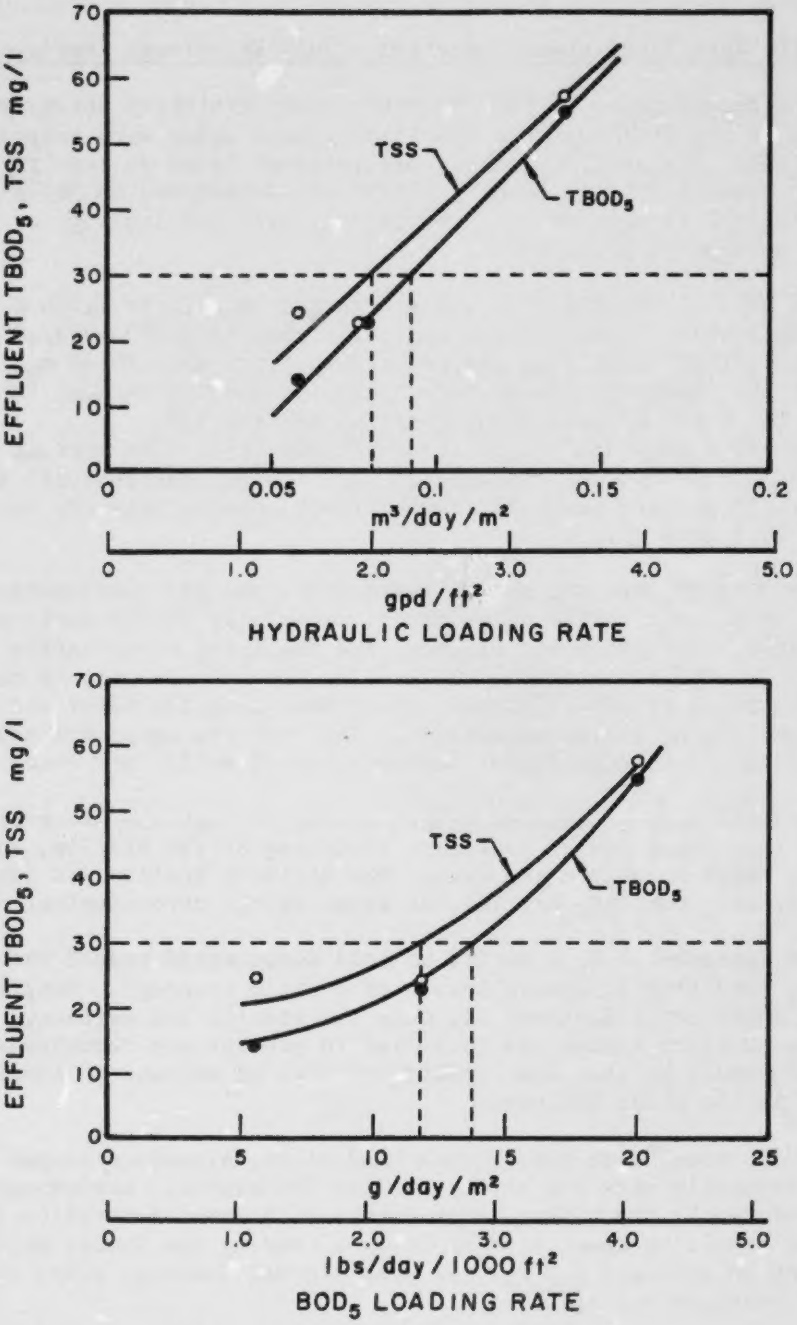


Figure 16. Summary of Phase I load evaluation performance

mended for steady state evaluation under both summer and winter conditions.

Phase II: Warm Temperature Operation - July 18 through September 25

The second phase of the Edgewater study evaluated steady state operation of the RBC/Underflow Clarifier system under warm temperature conditions. The optimum loading was selected based on results of Phase I. The results of this loading period are summarized on Table 3. Chronological records of daily monitoring data and loadings are displayed on Figures 17 to 19.

On July 1, the RBC flow was programmed to deliver 1,700 m^3/d (0.45 mgd) which represented a hydraulic rate of 0.093 $m^3/d/m^2$ (2.29 gpd/ft^2). This flow was reduced to 1,510 m^3/d (0.40 mgd) on July 30. Overall, the average hydraulic loading through the summer period was 0.085 $m^3/d/m^2$ (2.08 gpd/ft^2) and the BOD_5 loading was 11.4 $g/d/m^3$ (2.33 $lbs/day/1,000\ ft^2$). The average total effluent BOD_5 and TSS were 28 mg/l (79 percent removal) and 30 mg/l (75 percent removal), respectively, essentially the values predicted by Figure 16.

On July 28, the RBC system was drained and heavy accumulations of sludge were found on the false floor, especially in the early stages of the system. The floor was cleaned, and the first stage baffle was reinstalled. The clearance on all baffles was reduced from 18 cm (7 in) to 5 cm (2 in) to affect higher velocities along the floor and to minimize any further solids deposition. The tank was again drained in March 1978 and no significant accumulation of solids was observed.

An acid dump of unknown origin passed through the RBC system on August 15. There was an immediate sloughing of the biofilm, and then gradual build-up within ten days. The effluent quality was noticeably poor for only one day, day 161, as shown on the chronological figures.

On September 1-3, a series of acid dumps again passed through the system, resulting in severe losses of biofilm coverage. Sampling was discontinued until Septemer 11, when the biofilm had regrown. At this point a pH alarm system was installed to prevent any recurrence. The RBC pump would be shut down should any sign of extreme pH conditions appear in the plant influent.

Under these warm temperature conditions, dissolved oxygen levels were frequently very low throughout the RBC system. Low oxygen levels were induced by the higher temperatures with lower saturation levels and the resulting lower driving forces. During the summer months the influent DO averaged 1.5 mg/l at peak diurnal loading, while the effluent averaged 0.5 mg/l.

With the lower oxygen levels, the aerobic layer of the biofilm is reduced. The increased anaerobic layer may partially explain the intermittent recurrence of the filamentous organism beggiatoa through the

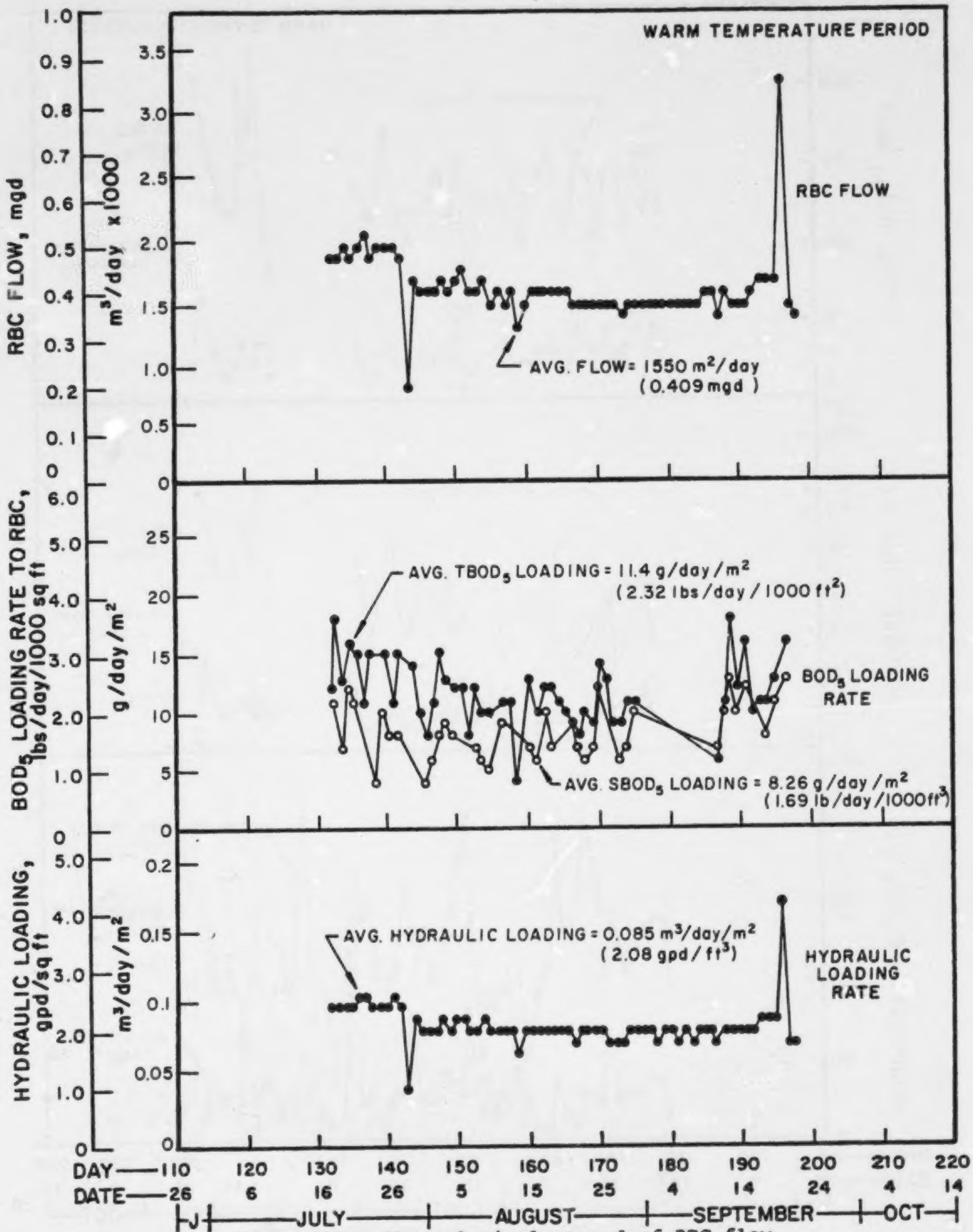


Figure 17. Chronological record of RBC flow, BOD_5, and hydraulic rates; Phase II (7/77-9/77)

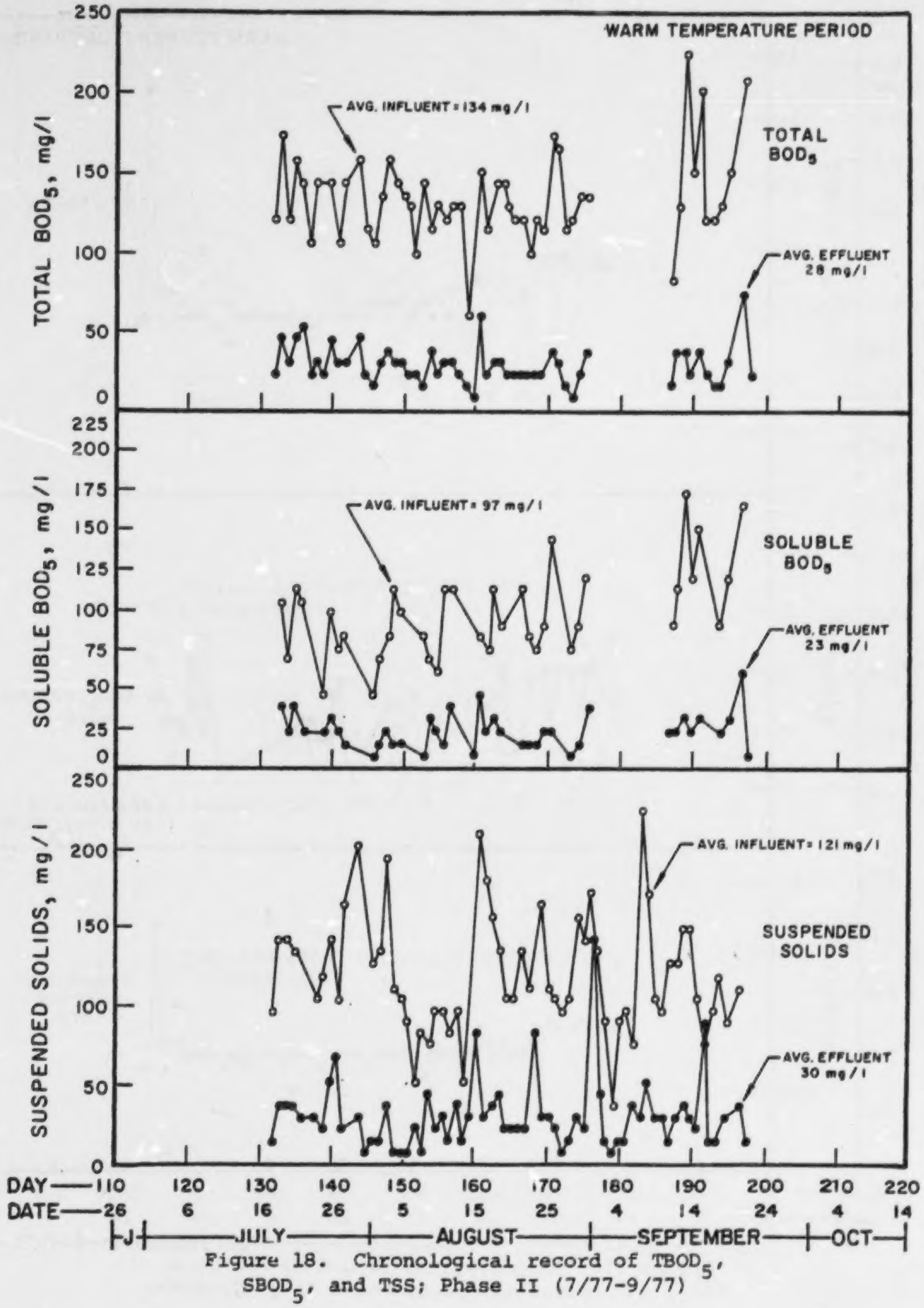


Figure 18. Chronological record of $TBOD_5$, $SBOD_5$, and TSS; Phase II (7/77-9/77)

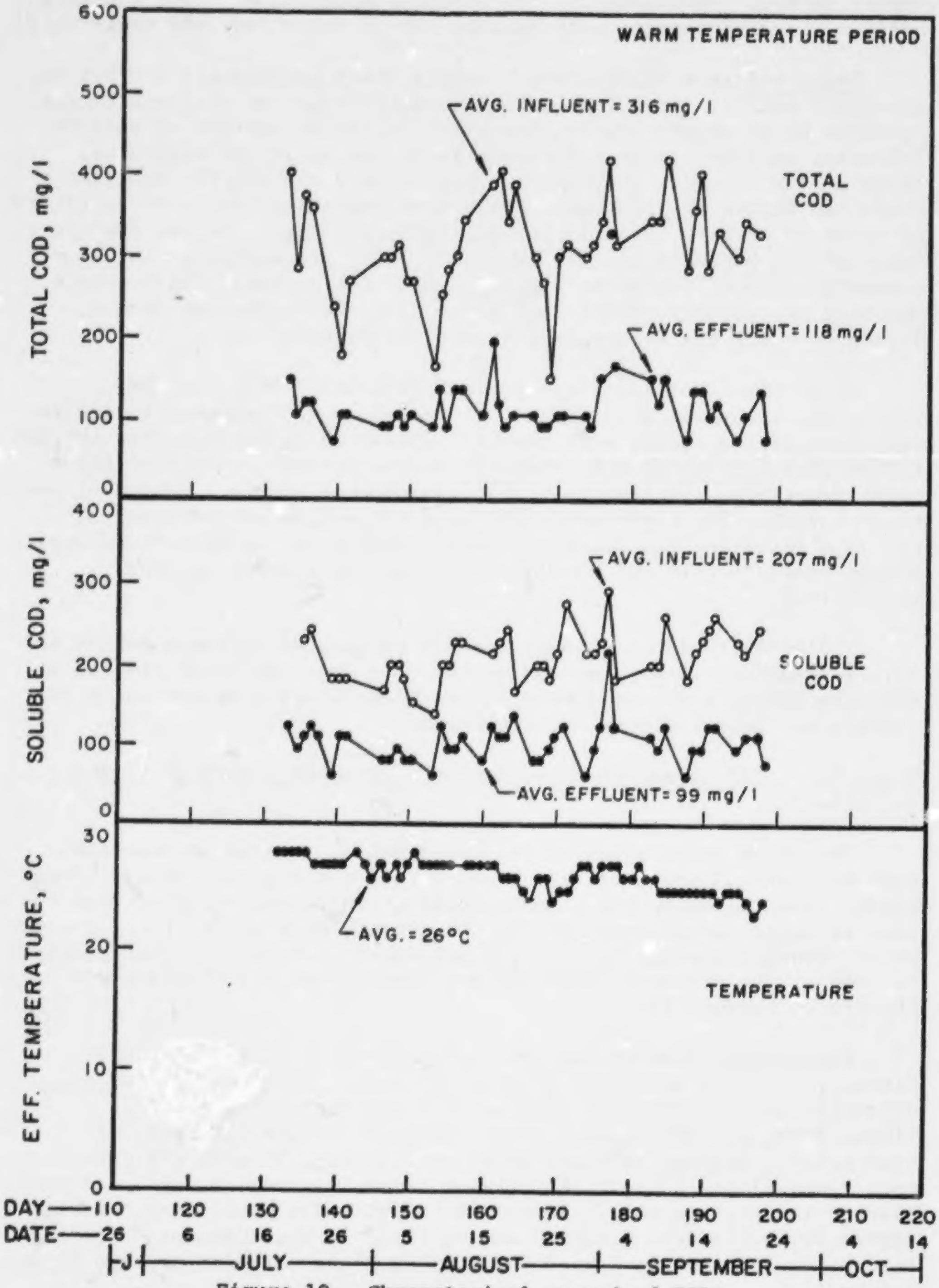


Figure 19. Chronological record of TCOD, SCOD and temperature; Phase II (7/77-9/77)

summer period. Additionally, the bacteria appeared at times when significant loading changes were imposed, as in early June and early July.

Beggiatoa is a filamentous bacteria which metabolizes sulfide to elemental sulfur. With low DO levels, sulfate may be utilized by the bacteria as an oxygen source, resulting in the production of sulfide. Increased sulfide levels are conducive to the growth of beggiatoa. Table A-3 in Appendix A summarizes the sulfate and sulfide analyses conducted during the program. These data indicated only minor activity in terms of sulfate reduction or sulfide production. During the occurrence of the bacteria in late September, H_2O_2 was evaluated as a possible remedy to remove beggiatoa from the system. The hydrogen peroxide was metered at a dosage of 40 mg/l over a 48-hour period. Within 24 hours the filamentous growth had disappeared.

As displayed on the chronological records of BOD_5 and TSS, Figure 18, treatment performance was not adversely impacted by the recurrences of the filamentous growth. Operating conditions with the RBC system were apparently not conducive to the extended growth of these bacteria. Typically the growth would disappear within a period of one to two weeks. The feeding of H_2O_2 into the system was successful in eliminating the bacteria, but depending on the degree and impact of the coverage, the use of H_2O_2 (or a similar remedy) may not be required.

Table A-2 in Appendix A presents a summary of nitrogen series analyses conducted throughout the study. The data indicated that at no time, including the summer months, was nitrification occurring to any significant degree within the RBC system.

Phase III: Cold Temperature Operation - December 1 through February 24, 1978

The third major phase of the experimental program at Edgewater evaluated steady state operation under cold temperature, winter conditions. The hydraulic and organic loading conditions selected were the same as those investigated during the summer, warm temperature, evaluation. Overall average results are presented on Table 3. Chronological records of the system's operation and performance are displayed on Figures 20 through 22.

The average flow during the period December 1, 1977 through February 24, 1978 was 1,490 m^3/d (0.393 mgd), which represented a hydraulic loading of 0.081 $m^3/d/m^2$ (2.0 gpd/ft^2). The influent $TBOD_5$ and TSS concentration averaged 158 and 133 mg/l, respectively. Average effluent $TBOD_5$ and TSS were 33 mg/l (79 percent removal) and 24 mg/l (82 percent removal), respectively, and the average temperature was 11.3 degrees C. With the lower temperatures, higher DO levels were measured during Phase 3; the influent DO during peak diurnal loading averaged 6.1 mg/l, and the effluent average DO was 3.4 mg/l.

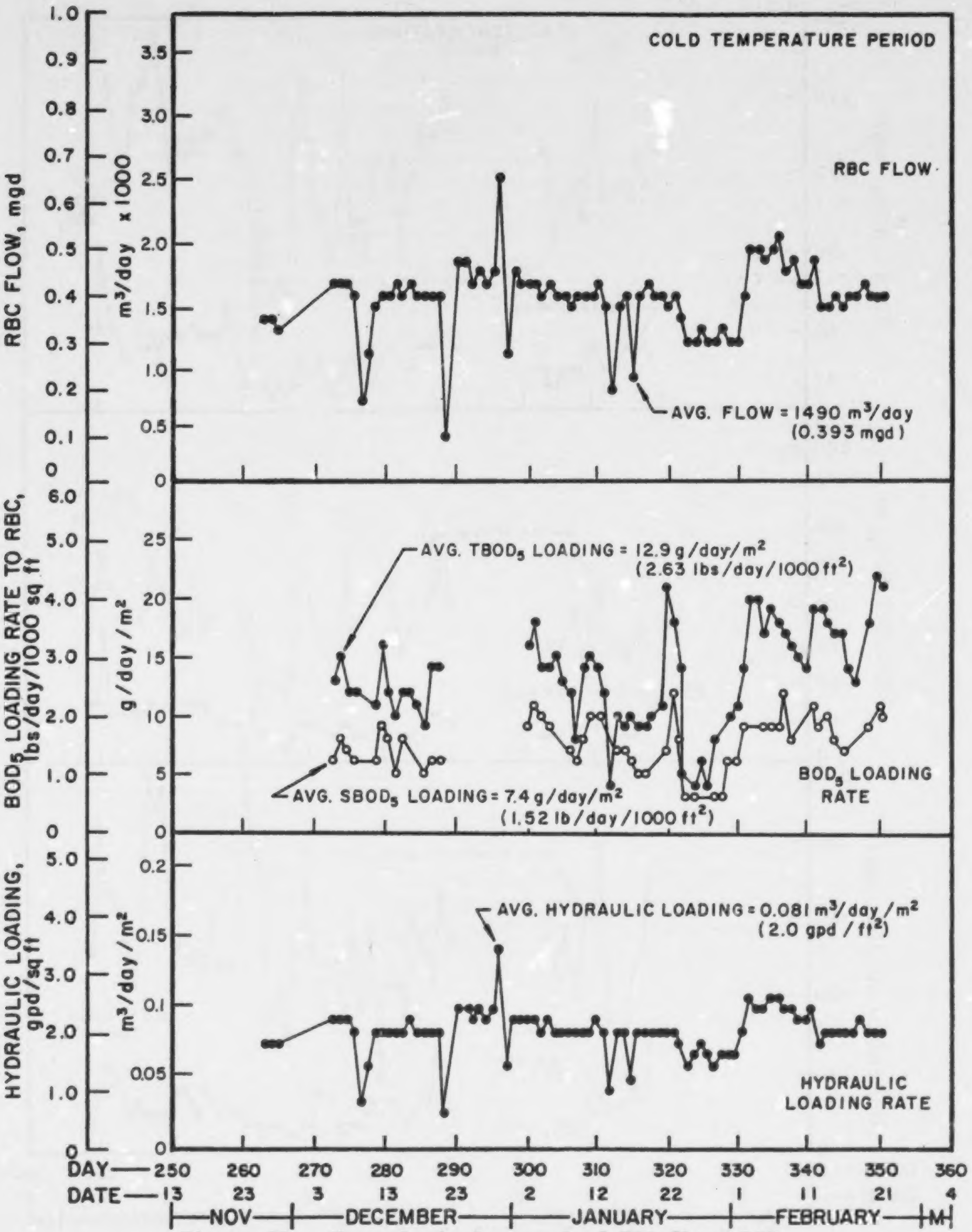


Figure 20. Chronological record of RBC flow, BOD_5, and hydraulic rates; Phase III (12/77-2/78)

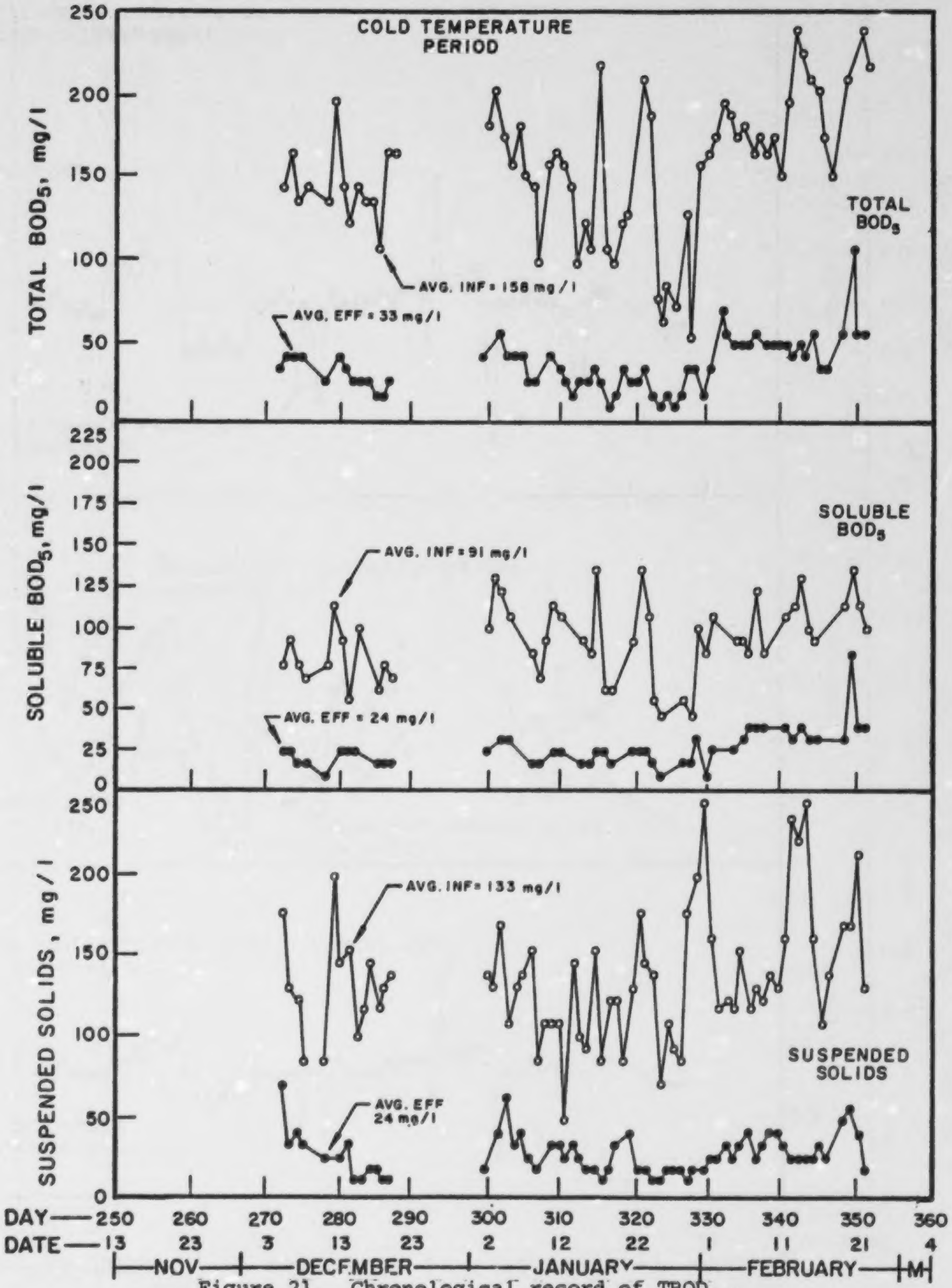


Figure 21. Chronological record of TBOD$_5$, SBOD$_5$ and TSS; Phase III (12/77-2/78)

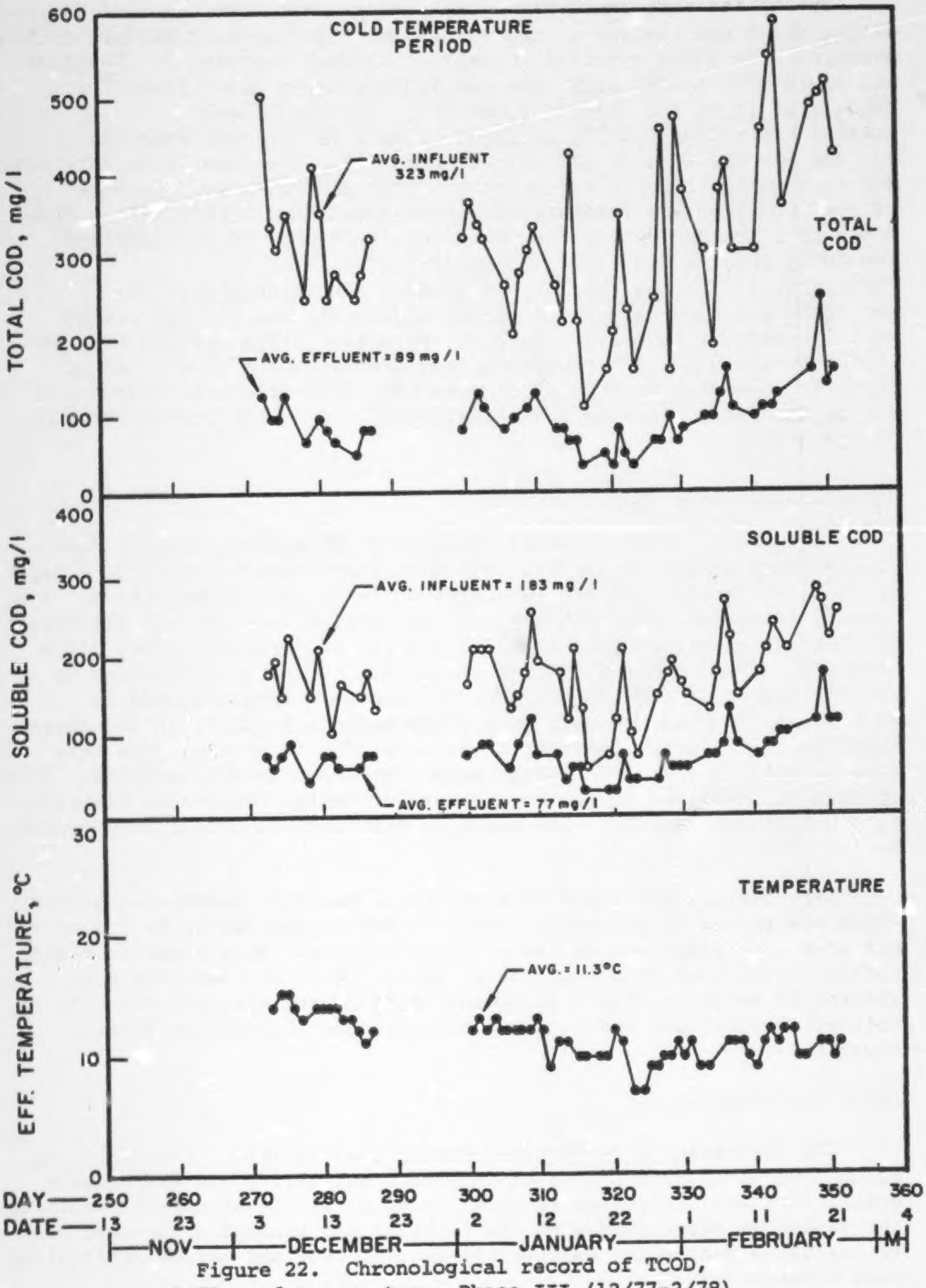


Figure 22. Chronological record of TCOD, SCOD, and temperature; Phase III (12/77-2/78)

During the cold temperature evaluation there were two periods during which the loading to the system was significantly different than average. The first occurred January 16 through February 3. The flow was 1,310 m^3/d (0.347 mgd), and the $TBOD_5$ loading was 9.53 g $TBOD_5/d/m^2$ (1.95 lbs·$TBOD_5/d/1,000\ ft^2$). At this lower loading the effluent $TBOD_5$ averaged 21 mg/l (82 percent removal) and the TSS was 15 mg/l (88 percent removal). The lower flow rate was due to a malfunction in the automatic programming valve. Once repaired, the flow was inadvertently readjusted to a higher rate. From February 4 through 14 the flow averaged 1,750 m^2/d (0.462 mgd) and the $TBOD_5$ loading was 17.3 g $TBOD_5/d/m^2$ (3.54 lbs $TBOD_5/d/ft^2$). During this higher loading condition the effluent $TBOD_5$ averaged 48 mg/l (73 percent removal) and the TSS was 29 mg/l (78 percent removal). Both of these monitoring periods were included in the overall averages discussed earlier and summarized on Table 3. However, it should be noted that the effluents observed during each were close to the values indicated by the curves shown on Figure 16.

Interstage Analysis of RBC System

Throughout the experimental program at Edgewater, 24-hour flow proportioned composite samples from each stage were analyzed on a regular basis. These data are tabulated on Table A-6 in Appendix A. A summary is presented on Table 8, and is divided into the six different periods representing specific RBC operating conditions. Since diffusion and reaction in the biofilm of the RBC system is a function of soluble organics, only the soluble COD and BOD_5 were measured in each stage. DO measurements were taken between 9 and 11 AM and represent the peak diurnal loading conditions. The interstage data were used to calibrate an RBC kinetic model developed by Hydroscience. This in turn was utilized in the development of design nomographs discussed in a subsequent section. The model is described in detail in Appendix B.

Essentially, the model is a series of material balance equations which are solved to determine substrate and oxygen levels in the effluent from each stage and in the attached biofilm. Mass transfer resistances, determined as a function of operating conditions, are considered in both the liquid phase and biofilm, and the reaction rate is related to substrate and oxygen concentrations through the kinetic equations.

Model Verification--

The interstage data obtained during the Edgewater study (and summarized on Table 8) was used to calibrate and verify the RBC kinetic model. The basic approach in this procedure was to establish values of the variables associated with the physical and biological process and to perform a search for appropriate removal rate and oxygen utilization rate constants.

TABLE 8. SUMMARY OF RBC INTERSTAGE DATA

Parameter (Averages)	ANALYSIS PERIODS 3/14-3/16 Low Loading Period	4/13-5/11 Moderate Loading Period	6/1-6/17 High Loading Period	6/22-7/1 High Loading Period	8/4-8/31 Warm Temp. Period	1/5-2/24 Cold Temp. Period
No. of stages	4	4	4	3	4	4
Flow, m^3/day (mgd)	1484 (0.392)	1450 (0.396)	2646 (0.700)	2752 (0.727)	1484 (0.392)	1514 (0.400)
Temp. (eff) oC	12.8	16.9	23.4	24.7	26.2	11.4
DO - Inf mg/1	8.5	5.4	1.7	2.0	1.5	5.9
St 1	4.5	3.2	1.5	1.2	0.8	4.8
St 2	4.4	2.5	1.1		0.6	3.7
St 3	4.2	2.3	0.9	0.9	0.5	3.2
St 4	4.0	1.7	0.6	0.5	0.7	3.3
BOD_5 T-inf mg/1	84	166	149	140	133	173
S-Inf	32	86	82	76	100	94
S-St 1	29	60	85	74	72	46
St 2	18	39	71		56	58
St 3	22	29	63	58	37	26
St 4	14	23	53	34	28	21
T-Eff	16	25	59	62	29	39
S-Eff	12	23	30	37	23	27
COD T-Inf mg/1	180	286	306	295	319	321
S-Inf	116	202	162	205	210	178
S-St 1	76	137	122	166	189	161
St 2	48	106	123	148	150	128
St 3	79	88	142	133	130	91
St 4	57	80	89	119	99	78
T-Eff	111	82	128	154	109	92
S-Eff	62	77	96	106	103	82
TSS Inf mg/1	145	115	129	127	126	141
St 1	292	104	124	113	142	190
St 2	246	125	293	215	256	266
St 3	403	117	112	86	123	169
St 4	218	224	306	115	156	131

Coupled Michaelis kinetics are used to simultaneously compute oxygen and substrate profiles through the fixed-film treatment process. The rate equations, which assume the reactions to occur exclusively in the biofilm layers, are as follows:

$$R_s = k \frac{S}{S + S_m} \quad \frac{C}{C + C_m} \qquad (1)$$

$$R_o = [a'k \frac{S}{S + S_m} + b'X_v] \frac{C}{C + C_m} \qquad (2)$$

where: R_s = rate of substrate removal (mg/l/min BOD_5)
R_o = rate of oxygen consumption (mg/l/min O_2)
S = Substrate (BOD_5 or COD) concentration (mg/l)
C = oxygen concentration (mg/l)
S_m = substrate Michaelis constant (mg/l BOD_5)
C_m = oxygen Michaelis constant (mg/l O_2)
k = maximum rate of substrate removal (mg/l/min BOD_5)
a' = oxygen utilization coefficient (mg O_2/mg BOD_5)
b' = endogenous reaction rate (mg O_2/mg VS/min)

The rate constant, k, is the combined term, $\mu X_v/Y$, where μ is the maximum specific growth rate, X_v is the biomass concentration, and Y is the organism yield coefficient. Because each is assumed constant in the model, a single rate constant (k) is employed.

Further model simplification was accomplished by using first order kinetics with respect to substrate. First order kinetics were induced by setting a high Michaelis half rate constant of 10,000 mg/l. Thus the term,

$$K \frac{S}{S + S_m} \qquad (3)$$

may be written (since $S_m >> S$),

$$\frac{kS}{S_m} \qquad (4)$$

The first order rate constant, k′, reported herein, is then defined as

$$k' = \frac{k}{S_m} = \text{min}^{-1} \qquad (5)$$

The model input provides a description of the physical system, which includes the number of stages, surface area, tank volume, rotational speed, and hydraulic loading rate. Input necessary in the description of the biological process includes influent organic loading, dissolved oxygen levels, substrate and oxygen diffusion rates and coefficients describing substrate and oxygen utilization.

Temperature corrections for the removal rate constant was defined by the relationship

$$K_T = K_{20}\ C^{\O(T - 20)}$$

where Ø was set at 1.04. Diffusivities were corrected for temperature by an equivalent Ø of 1.028. The endogenous oxygen utilization rate, b', was corrected for temperature by an equivalent Ø of 1.1.

Figures 23 and 24 show the final verification results for each of the six study periods. As shown in the figures, the model was able to effectively predict soluble BOD_5 and DO profiles through the system using a single set of kinetic parameters for all cases. Equivalent model predictions were made for the interstage soluble COD data, as shown on Figure 25. Oxygen profiles were not shown for the COD verification runs. They were very similar to those shown on Figures 23 and 24 for the BOD_5.

The kinetic parameters found appropriate were as follows:

k' = 0.3 min^{-1} at 20°C, Ø = 1.04
a' = 0.65 mg O_2/mg BOD_5 removed
a' = 0.4 mg O_2/mg COD removed
b' = 0.2 day at 20°C, Ø = 1.1
X_v = 40,000 mg/l
S_m = 10,000 mg/l
C_m = 0.001 mg/l

A $k' = 0.3\ min^{-1}$ represents a maximum removal rate k (equation 1) of 3,000 mg/l-min. When COD was used as the substrate input, a non-degradable fraction of 30 mg/l was assumed. On Figures 23, 24 and 25, HL and SL represent the hydraulic and soluble organic loading rates, respectively. The effective (wetted) surface area of Stages 1, 2 and 3 is 4,000 m^2 (43,000 ft^2); the Stage 4 surface area is 6,200 m^2 (66,700 ft^2).

The oxygen concentrations presented in Table 8 and on Figures 23 and 24 represent measurements taken between 9 AM and 11 AM each day, at which time the loading to the system is greatest. The oxygen profiles generated by the model are based on peak loading conditions. The peak conditions are based on the maximum to average conditions determined from the diurnal studies described in Section 6, whereby the hydraulic loading is increased by a factor of 1.5 times the average, and the average substrate and solids (interstage) levels are increased by a factor of 1.7. Additionally, the average dissolved oxygen profile predicted under average conditions is shown on each of the displays, on Figures 23 and 24. The BOD_5 and COD verifications shown are based on average daily loadings.

It is concluded from this analysis that the model is capable of predicting system performance over a range of hydraulic and organic

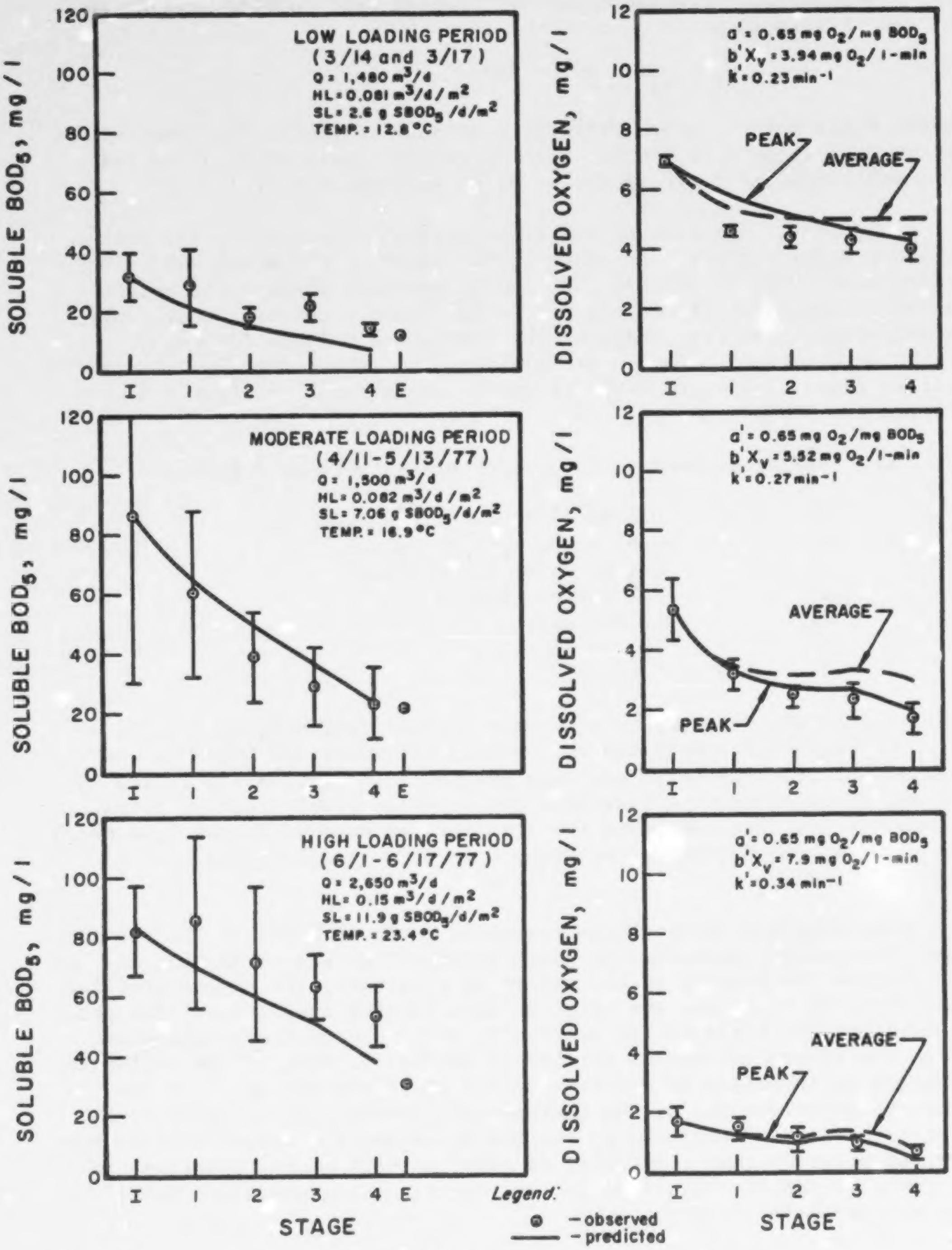


Figure 23. RBC kinetic model verification based on interstage $SBOD_5$ and D.O. data

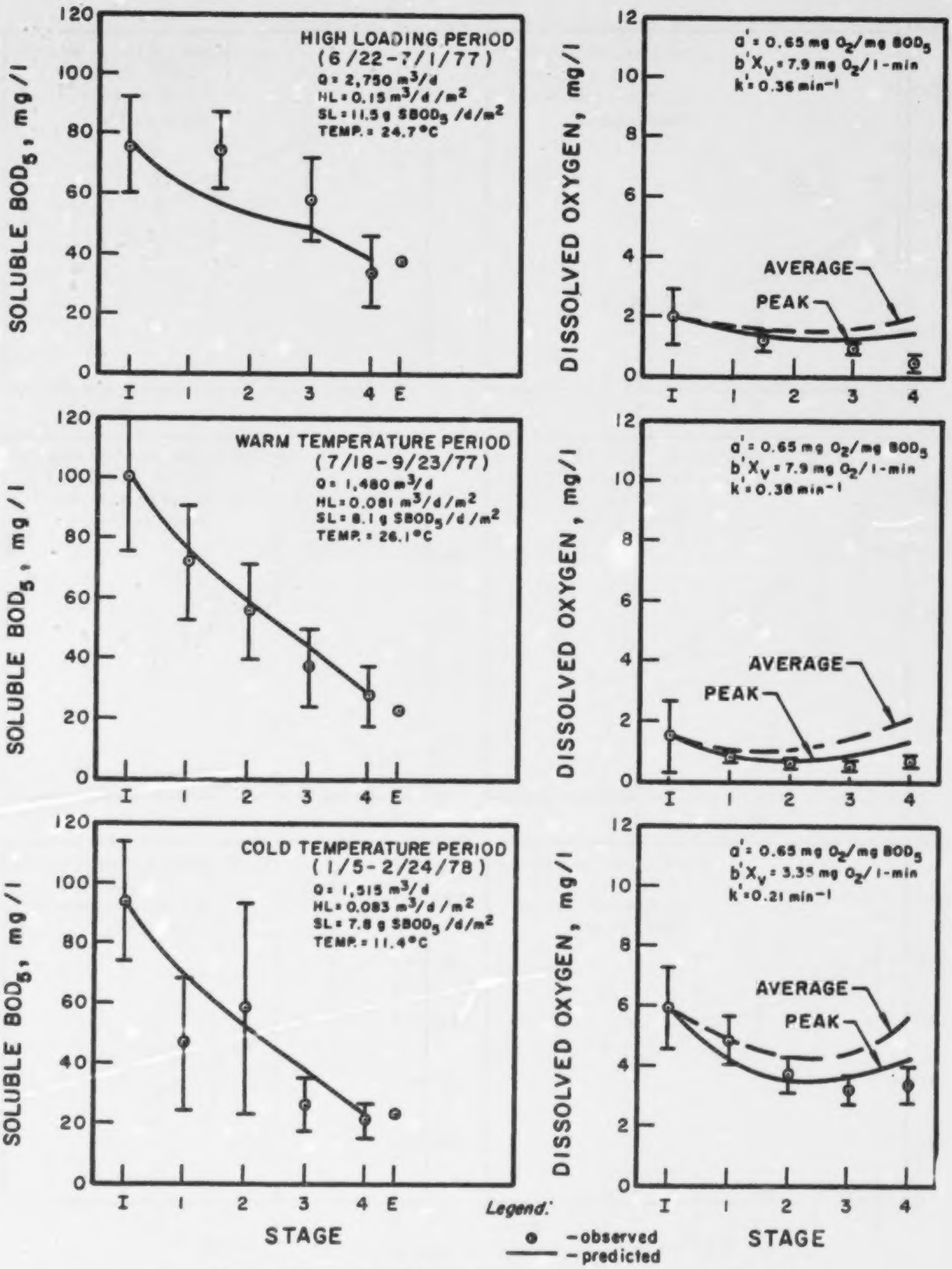


Figure 24. RBC kinetic model verification based on interstage SBOD$_5$ and D.O. data

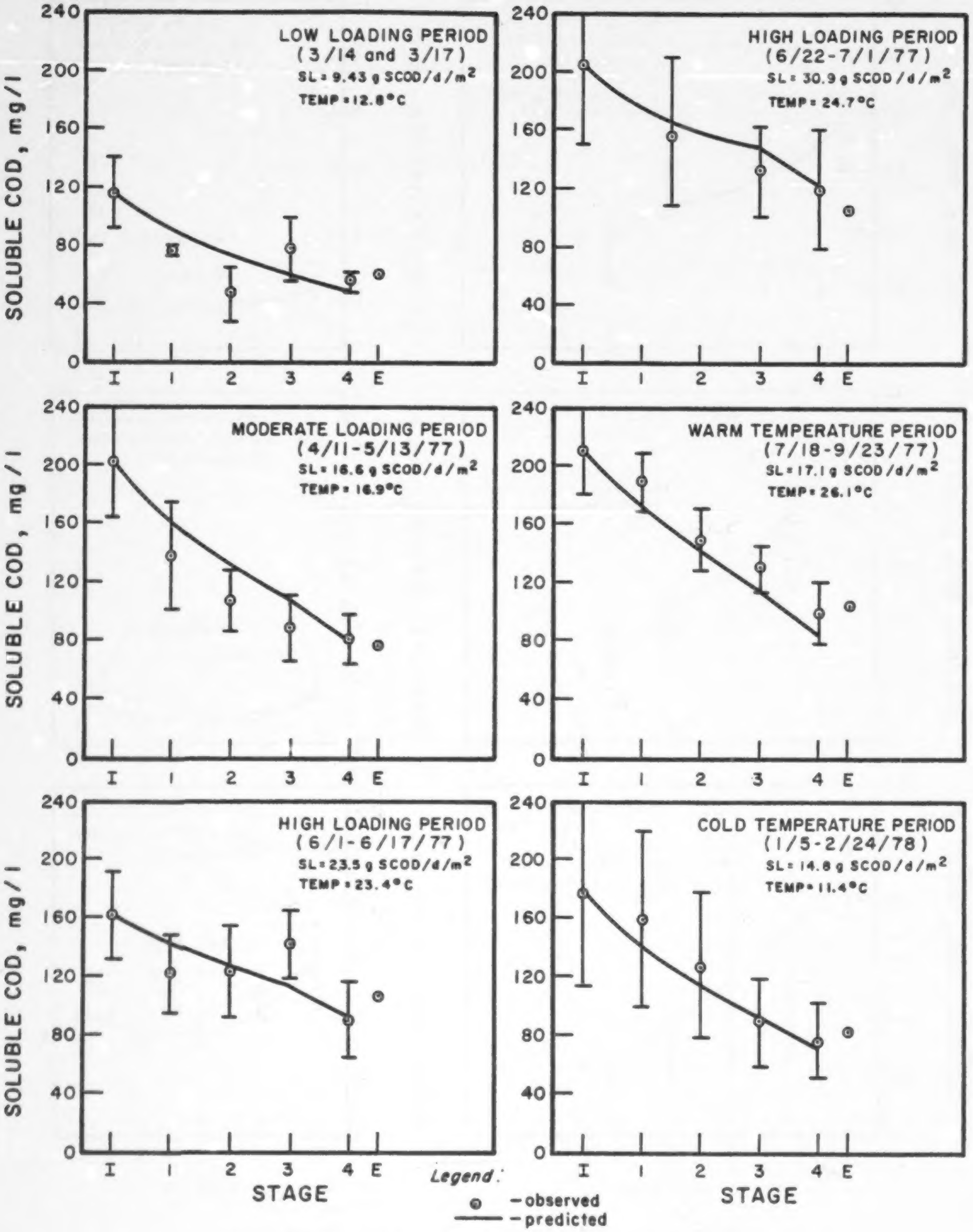


Figure 25. RBC kinetic model verification based on interstage COD data

loading conditions using a single set of kinetic parameters, k′, a′ and $b'X_v$. The match of the observed data indicates that hydraulic and mass transfer components respond correctly to system variations.

Oxygen Utilization

A primary role of the rotating media is to provide an effective means for oxygenation of the fixed biofilm and prevent anoxic or oxygen-limiting conditions in the removal of substrate. The system can be approximated by a COD balance (assuming minimal autotrophic activity) which estimates the total oxygen utilization for both substrate oxidation and cell synthesis:

$$O_2 \text{ Utilization} = \text{RBC Influent COD} - \text{Effluent COD} - \text{COD Wasted}$$

The term (influent COD - effluent COD) is effectively the TCOD removal rate and is presented on Figure 26 as a function of TCOD loading to the system. The COD wasted can be estimated from the daily sludge wasting data and the estimated COD/TSS ratio of 1.0 (Table 7), whereby the mass of solids wasted per day (combined primary and sloughed solids drawn from sludge hopper on a daily basis) is converted to an equivalent oxygen mass. This COD equivalent was then subtracted from the COD removal rate and plotted as the net oxygen utilization rate, as shown on Figure 26. The oxygen utilization rate, as predicted by the kinetic model is also shown on Figure 26, and corresponds closely with the curve based on the COD balance.

The shape of the O_2 utilization curve on Figure 26 is similar to the organic removal rate curve shown on Figure 33. The flattening of the rates at the higher influent loadings suggest the system is reaching a limiting condition in its ability to transfer oxygen.

The RBC model is capable of constructing oxygen and substrate profiles through the RBC stages and into the biofilm. Figure 27 presents an example of biofilm $SBOD_5$ and DO profiles in Stage 1 under the high loading condition of 91 g $BOD_5/d/m^2$ (18.6 lbs BOD_5/ d/1,000 ft^2). The kinetic equations used in the model (see equations 1 and 2) cause a reduction in substrate removal rate when the ratio $C/(C + C_m)$ drops significantly below unity. Thus, if the DO is less than the Michaelis constant ($C < C_m$) in regions of the biofilm, the reaction is limited by a deficiency of oxygen. Figure 27 is an example of this. Substrate concentrations are in excess of 44 mg/l $SBOD_5$ throughout the biofilm, and oxygen concentrations dropped below 0.001 mg/l at biofilm depths in excess of 350μ m. Therefore, for all practical purposes, the active biomass depth in Stage 1 is 350μ m, beyond which substrate removal is minimal.

Active Biofilm

Figure 28 presents an estimation of active biofilm depth for each stage under high and moderate loading conditions. Only sector five is presented. As indicated on Figure B-1 (Appendix B), Sector 5 is that

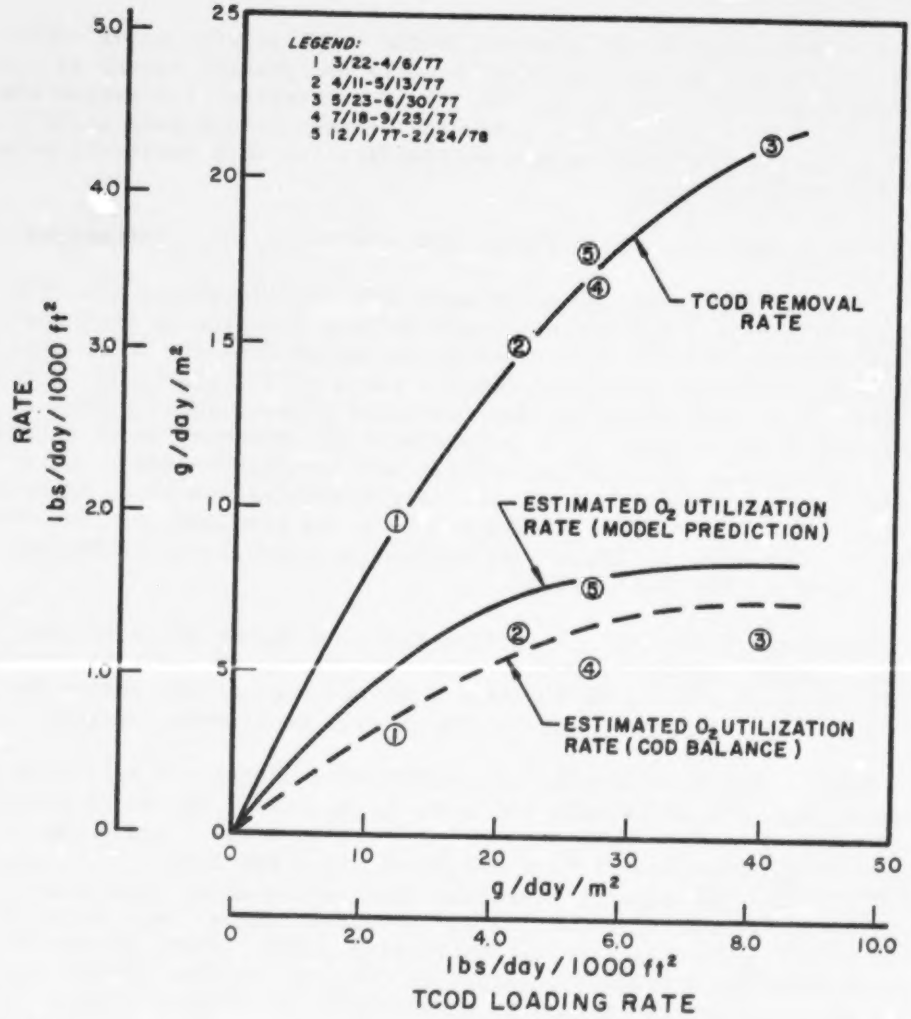
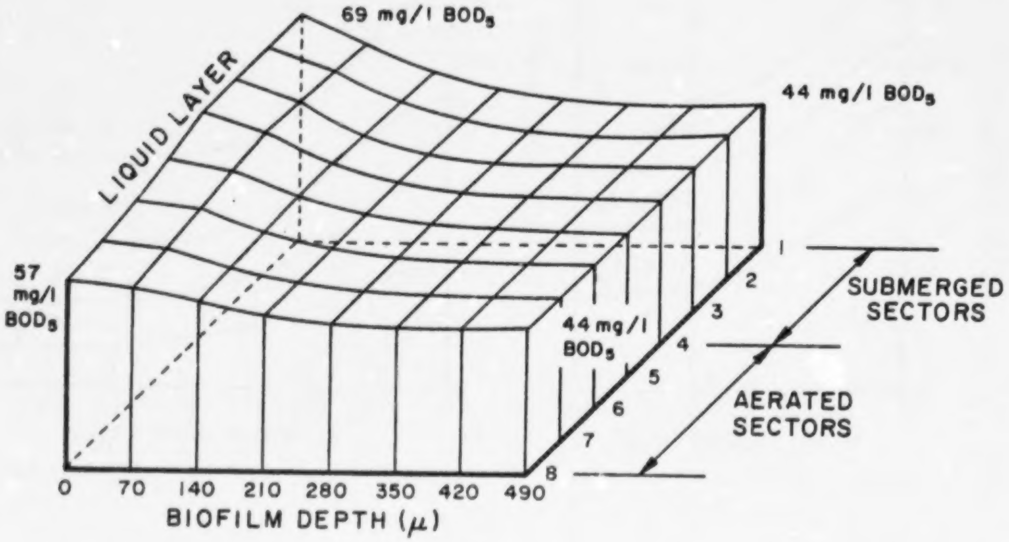
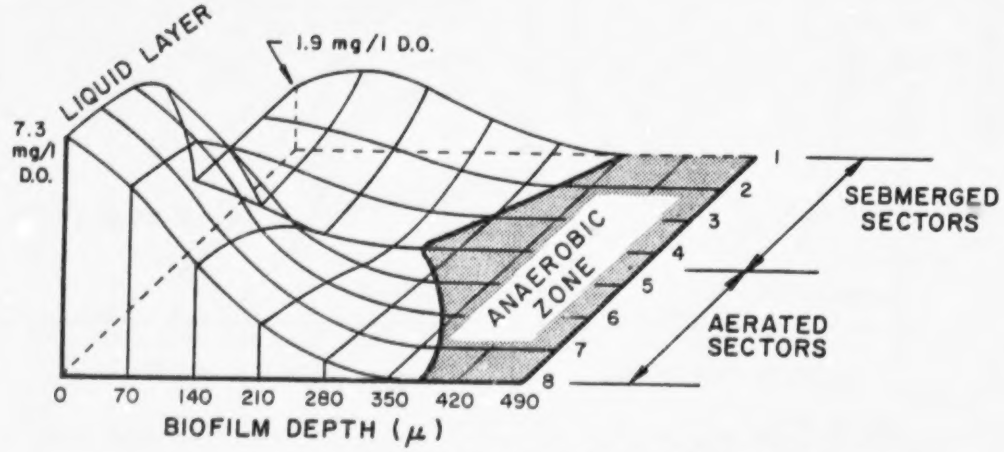


Figure 26. Estimate of RBC oxygen utilization rates

SOLUBLE BOD_5 WITHIN BIOFILM

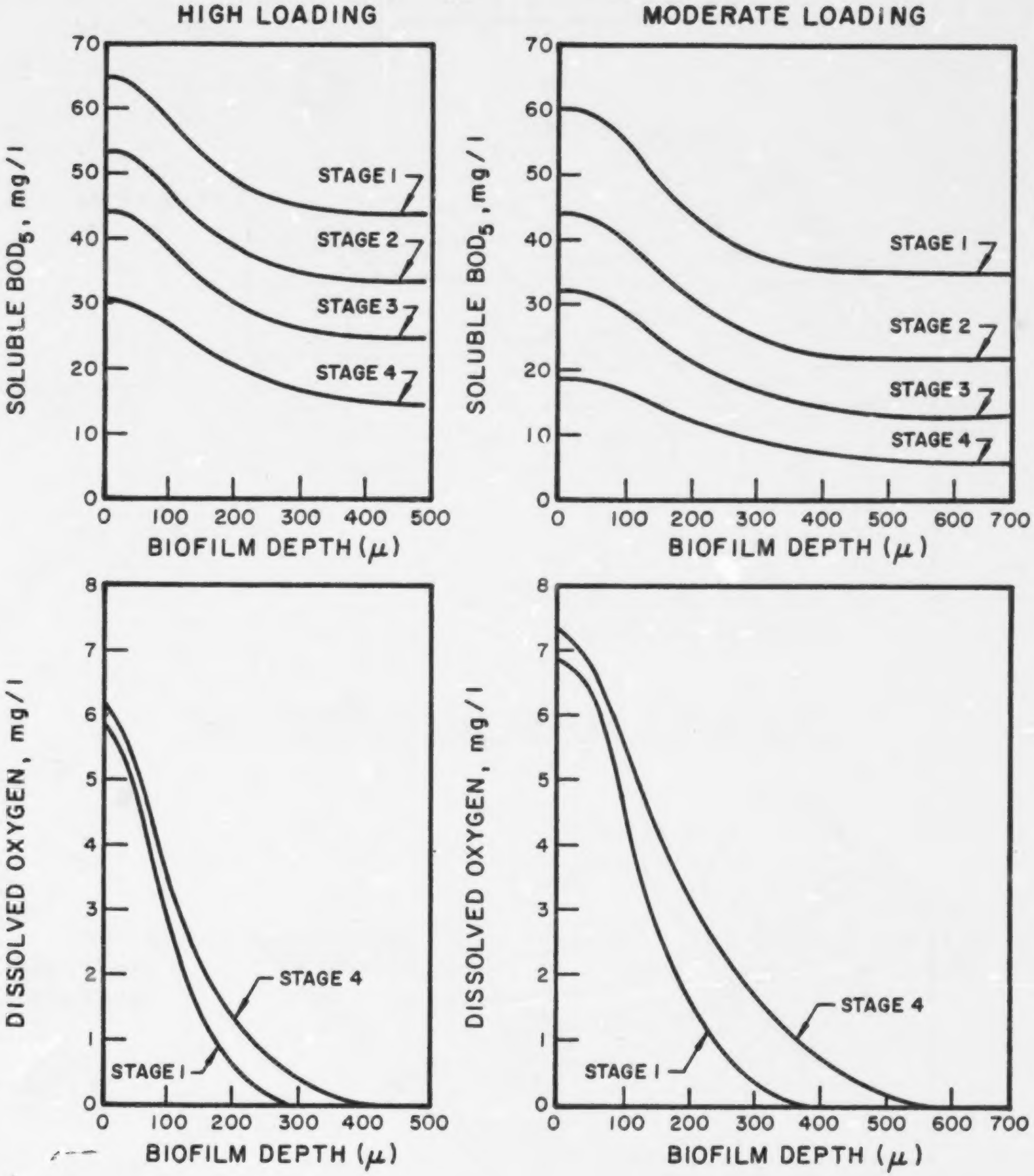


DISSOLVED OXYGEN WITHIN BIOFILM



STAGE 1 SUBSTRATE LOADING = 91 g/day/m^2
(18.6 lbs/day/1000 ft^2)

Figure 27. Predicted substrate and oxygen profiles in biofilm



HYDRAULIC LOAD = 0.14 $m^3/d/m^2$
SOLUBLE SUBSTRATE LOAD = 10.4 $g/d/m^2$

HYDRAULIC LOAD = 0.08 $m^3/d/m^2$
SOLUBLE SUBSTRATE LOAD = 7.7 $g/d/m^2$

Figure 28. Biofilm concentrations of substrate and dissolved oxygen in successive stages

segment of the disc subsequent to emergence from the liquid, and represents a near minimum active layer segment. The data show a slowdown of the substrate removal reaction as the DO approaches limiting conditions.

As shown on Figure 28, the active film layer is between 300 and 600 µm, typically dictated by oxygen limiting conditions, and dependent upon loading conditions. This suggests that excessive growth of biofilm does not result in additional substrate removal. This was observed in the late summer months when acid dumps caused considerable sloughing of the attached growth. Effective treatment was still maintained with a relatively thin biofilm. A judgment as to whether the biofilm in excess of the active depth is useful is difficult. While it adds considerably to the mass to be supported by the shaft, the large solids inventory may serve to control net solids production by anaerobic endogenous respiration.

Seasonal Effects

An important consideration in the summer and winter evaluations was the overall impact of temperature on treatment efficiencies. Average effluent temperatures were 26°C and 11°C during the summer and winter periods, respectively, representing a total differential of 15°C.

Table 9 presents a portion of the data obtained during these periods. A complete data tabulation is presented in Table 3.

TABLE 9. COMPARISON OF SUMMER AND WINTER PERFORMANCE

		Summer 7/18/77-9/25/77	Winter 12/1/77-2/24/78
Hydraulic loading			
$m^3/d/m^2$		0.085	0.081
(gpd/ft^2)		(2.08)	(2.0)
$TBOD_5$ loading			
$g/d/m^2$		11	13
($lb/d/1,000\ ft^2$)		(2.3)	(2.6)
RBC Influent BOD_5	T	134	158
mg/l	S	97	91
Effluent BOD_5	T	28	33
	S	23	24
$TBOD_5$ removal (%)		79	79
$SBOD_5$ removal (%)		76	74

The above results indicate that under equivalent loading conditions, similar removal efficiencies (as expressed by percent removal) were experienced during both the summer and winter evaluation periods.

Temperature will affect several of the mechanisms involved in the kinetics of the fixed film process, including substrate removal rates, oxygen saturation values (hence, mass transfer driving forces), and the diffusivities oxygen and substrate. As discussed earlier, each of these kinetic parameters were corrected for temperature in the kinetic model verification.

The minimal impact of temperature on system performance is due to compensating effects of the various parameters affected by temperature. Thus, the higher removal rates and diffusivities experienced in the summer were offset by the low dissolved oxygen levels and the lower dissolved oxygen saturation value. In the winter, the lower kinetic removal rates were compensated by high influent dissolved oxygen concentrations and higher dissolved oxygen saturation values: since dissolved oxygen penetration was found to be the limiting factor (as graphically displayed on Figures 27 and 28), imposition of high dissolved oxygen concentrations and/or higher dissolved oxygen saturation values will effectively increase the oxygen driving force, increase the active film thickness and result in increased substrate removal. Thus, although one would expect lower substrate removals during the winter due to suppression of the kinetic removal rate, the increased oxygen driving force provides effective compensation, resulting in substrate removals similar to that of the summer.

As an example, Figure 29 presents substrate, DO, and active film layer profiles through a four-stage system under the following conditions:

Influent $SBOD_5$ = 100 mg/l
Influent Flow = 1,510 m^3/d (0.4 mgd)
Influent DO = 0.0 mg/l
Temperature = 25°C

The kinetic coefficients k′, b′, a′, and the diffusivities have all been adjusted to equivalent rates at 25°C. The two solutions shown on Figure 29, however, represent oxygen saturation values of 8.4 mg/l and 11.3 mg/l. As can be seen, by simply increasing oxygen solubility, the oxygen driving force is increased, increasing the depth of diffusion into the biofilm, with subsequently higher substrate utilization.

Underflow Clarifier Performance

Beyond the fourth shaft (refer to Figure 4), the RBC/Underflow Clarifier system effectively consists of two distinct sectors, the turnaround sector and the underflow clarifier sector. Tracer analyses indicated that the entire turnaround sector behaved as a completely mixed system. The studies showed that the mixing characteristics of the turnaround sector effectively reduced the volume nominally associated with the underflow clarifier from 100 to 75 m^3 (26,000 to 20,000 gallons), or by approximately 25 percent. The nominal surface area, i.e., that which is below the intermediate floor is 72.8 m^2

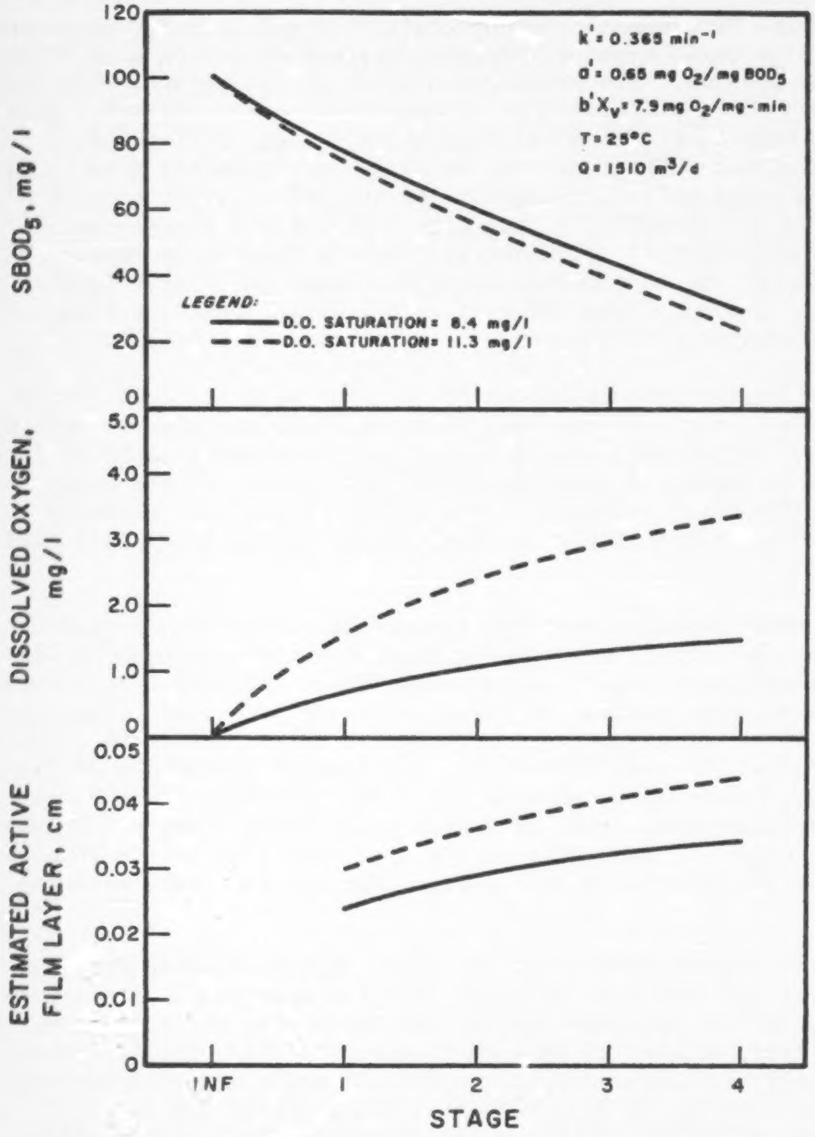


Figure 29. Evaluation of impact of dissolved oxygen gradients on substrate removal

(784 ft^2). Based on the estimated 25 percent reduction, the available, or effective, surface area becomes 54.6 m^2 (588 ft^2).

Figure 30 presents the correlation of effluent TSS as a function of overflow rate, based on average observed data from each of the major sampling periods. The correlation shown on the Figure, while not particularly uniform, implies an allowable effective clarifier overflow rate between 22 and 26 $m^3/d/m^2$ (550 and 650 gpd/ft^2) to obtain an effluent TSS less than 30 mg/l. At Edgewater this is equivalent to a hydraulic loading rate to the RBC of 0.065 to 0.08 $m^3/d/m^2$ (1.6 to 1.9 gpd/ft^2), assuming an effective surface area of 54.6 m^2 (588 ft^2). The overall average TSS in the fourth stage during the experimental program (based on thirty-eight 24-hour composite analyses) was 160 mg/l. The percent removals shown on Figure 30 are based on a fourth stage concentration of 160 mg/l.

During the interim period between the warm and cold temperature evaluations, i.e., October and November 1977, experiments were conducted to determine if the settling characteristics could be improved, thereby increasing the solids capture efficiency of the underflow clarifier. The tests centered on evaluation of chemical addition to the fourth stage mixed liquor, relying on the mixing provided by the fourth shaft.

A number of coagulant and flocculant aids were screened by standard jar test procedures to determine an effective chemical additive, and approximate dosage requirements. These included ferric chloride, alum, lime, combinations of ferric chloride with lime, alum with lime, and a series of polymers. The tests indicated that ferric chloride addition was the most effective. A series of flocculant settling tests were then conducted to confirm the effectiveness of ferric chloride, using samples drawn from the fourth stage mixed liquor. The upper display on Figure 31 demonstrates the improvement in solids removal at a dosage of 20 mg/l $FeCl_3$, as derived from the lab scale settling tests.

A full-scale evaluation was undertaken by feeding $FeCl_3$ directly to the fourth stage. The solution was evenly distributed across the tank on the upstream side of the fourth RBC shaft. During the control period, October 20 through November 9, 1977, the flow was set at a relatively high rate of 2,200 m^3/d (0.58 mgd), which represented a hydraulic loading of 0.12 $m^3/d/m^2$ (2.95 gpd/ft^2) and an effective secondary clarifier overflow rate of 40 $m^3/d/m^2$ (980 gpd/ft^2). The effluent TSS during this period averaged 39 mg/l.

The ferric chloride was metered to the fourth stage from November 10 through November 21, 1977 at dosages increasing from 20 mg/l to 75 mg/l $FeCl_3$. The average flow was 2,240 m^3/d (0.593 mgd). The average effluent TSS during this time was 46 mg/l, indicating no improvement in solids capture with addition of the ferric chloride. Subsequent bench scale flocculant settling tests demonstrated that the

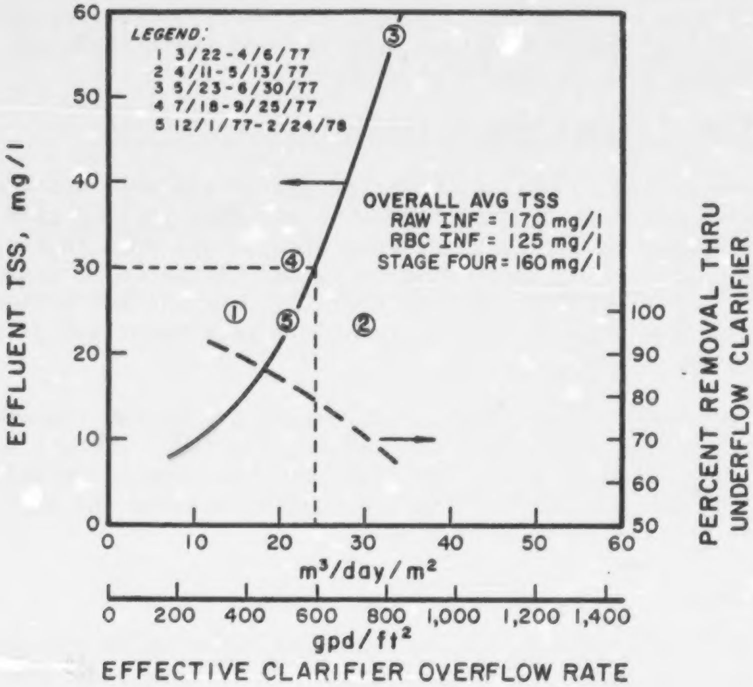


Figure 30. Correlation of effective TSS with effective clarifier overflow rate

problem was attributable to inadequate mixing in the fourth stage. The lower display on Figure 31 presents these data. Unless adequate agitation is provided initially for proper contact between waste solids and the coagulant, the effect of chemical addition will be minimal. The bench scale data on Figure 31 suggests that ferric chloride effectively improves settling characteristics when applied under rapid mix conditions, followed by a period of slow mixing.

RBC/Underflow Clarifier Removal Efficiency Correlations

Figures 32 and 33 present correlations of effluent TSS and organic removal rates with the overall hydraulic and BOD_5 loading rate, respectively (based on effective surface area). The data represent averages of each of the indicated study periods. As shown, a reasonable correlation exists with respect to hydraulic loading and effluent solids, while the organic loading rate is more appropriate in predicting the removal of BOD_5.

As discussed earlier, due to compensating effects, temperature, as described by summer and winter conditions, was found to have minimal impact on removal efficiency. In light of this, the correlations presented on Figures 32 and 33 reflect actual conditions and have not been adjusted for differing temperatures.

Solids Handling

Figure 34 presents weekly average data relating to the inventory of influent, effluent, and waste solids. These data indicate, as expected, increasing inventories with increasing BOD_5 removal rates. Addition of the effluent solids and waste solids yields the total sludge wastage. This is correlated with the total BOD_5 removal rate on Figure 35.

Figure 36 presents a correlation of net solids produced (computed by subtracting the influent solids inventory from the total sludge wastage) to the soluble BOD_5 removal rate. As shown, between the normal operating range of 5 to 7.5 g $SBOD_5$ removed/d/m^2 (1.02 to 1.53 lbs/d/1,000 ft^2), there was a net solids growth between 1.0 and 7.5 g SS/d/m^2 (0.20 and 1.53 lbs/d/1,000 ft^2).

Nutrients

Tables A-2 and A-5 tabulate the nitrogen and phosphorus analyses conducted throughout the experimental program. The nitrogen data are further summarized on Table 3. The data confirm non-limiting conditions with respect to either nitrogen or phosphorus. A prime objective in the frequent analysis for the nitrogen series was to monitor the occurrence of nitrification, especially in the warm temperature months and in the latter stages. As shown, nitrification did not occur at any time during the entire experimental period.

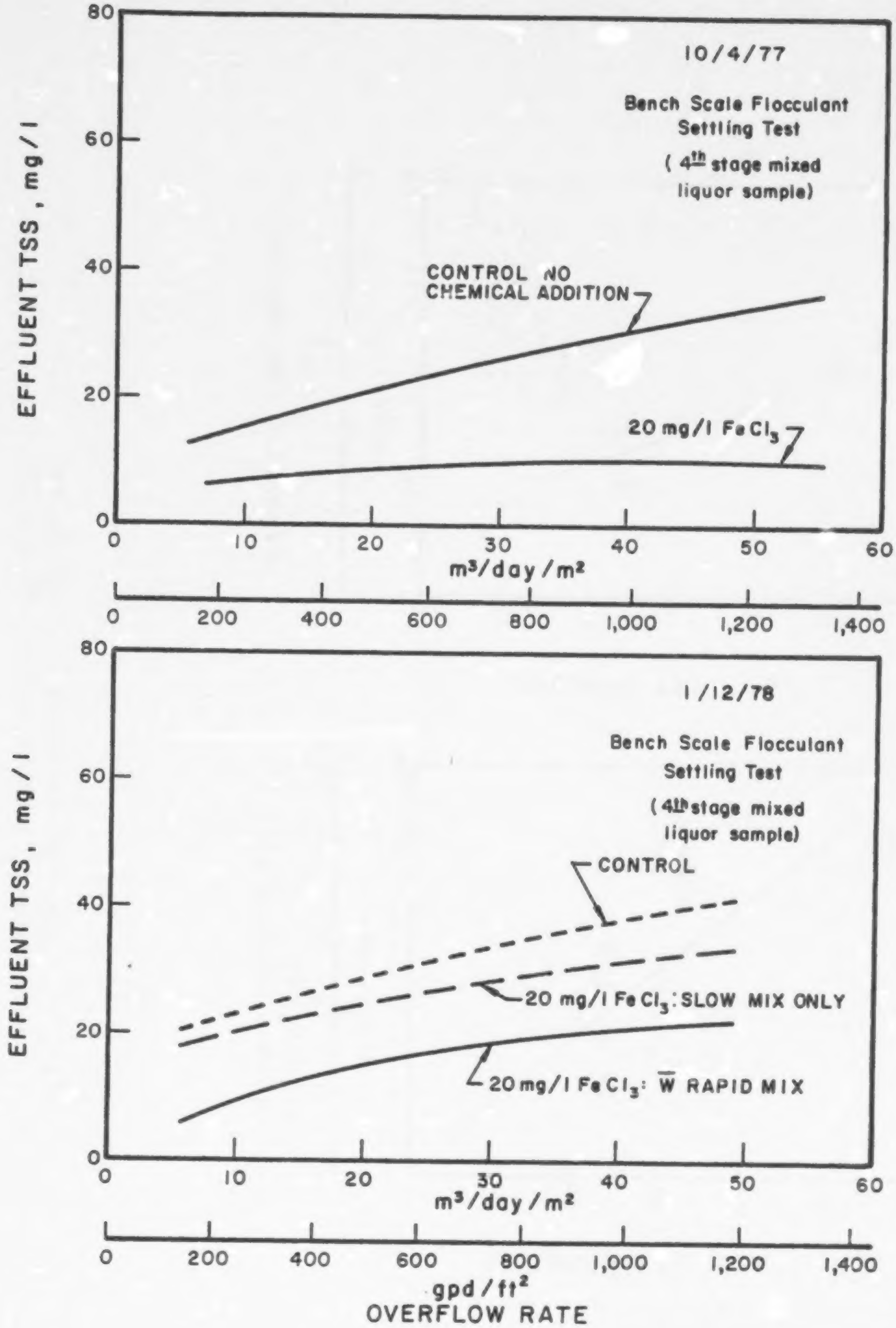


Figure 31. Evaluation of chemical treatment for improved solids capture

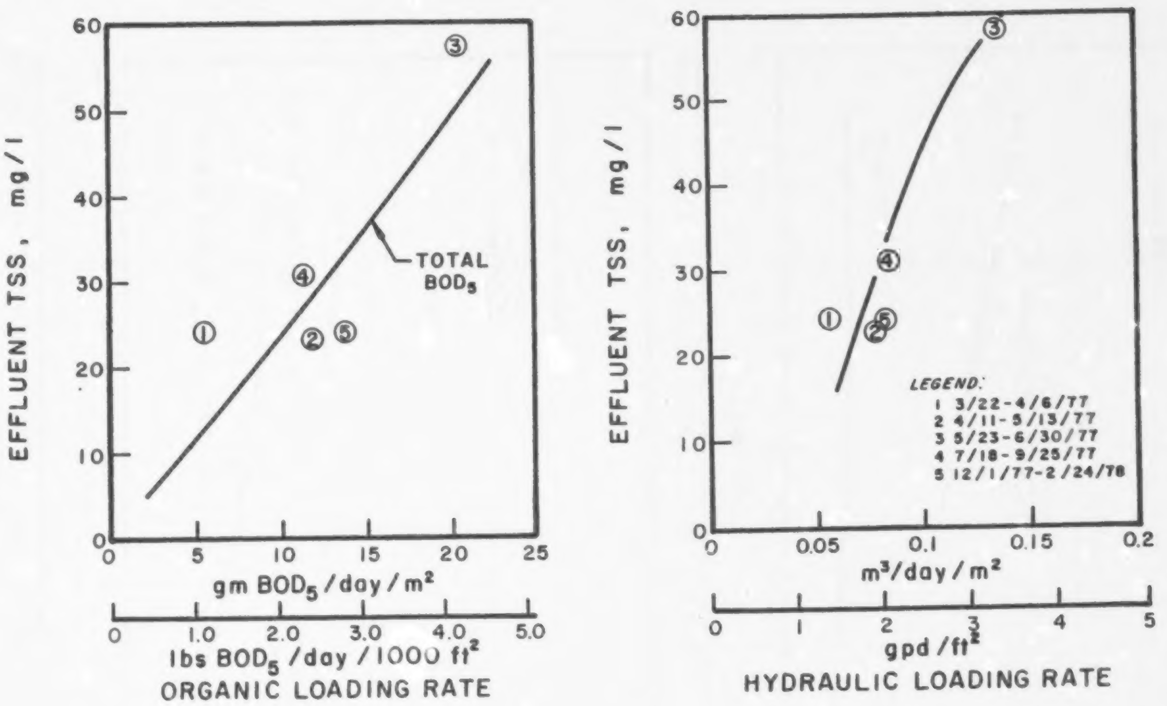


Figure 32. Correlation of organic and hydraulic loading rate to effluent TSS

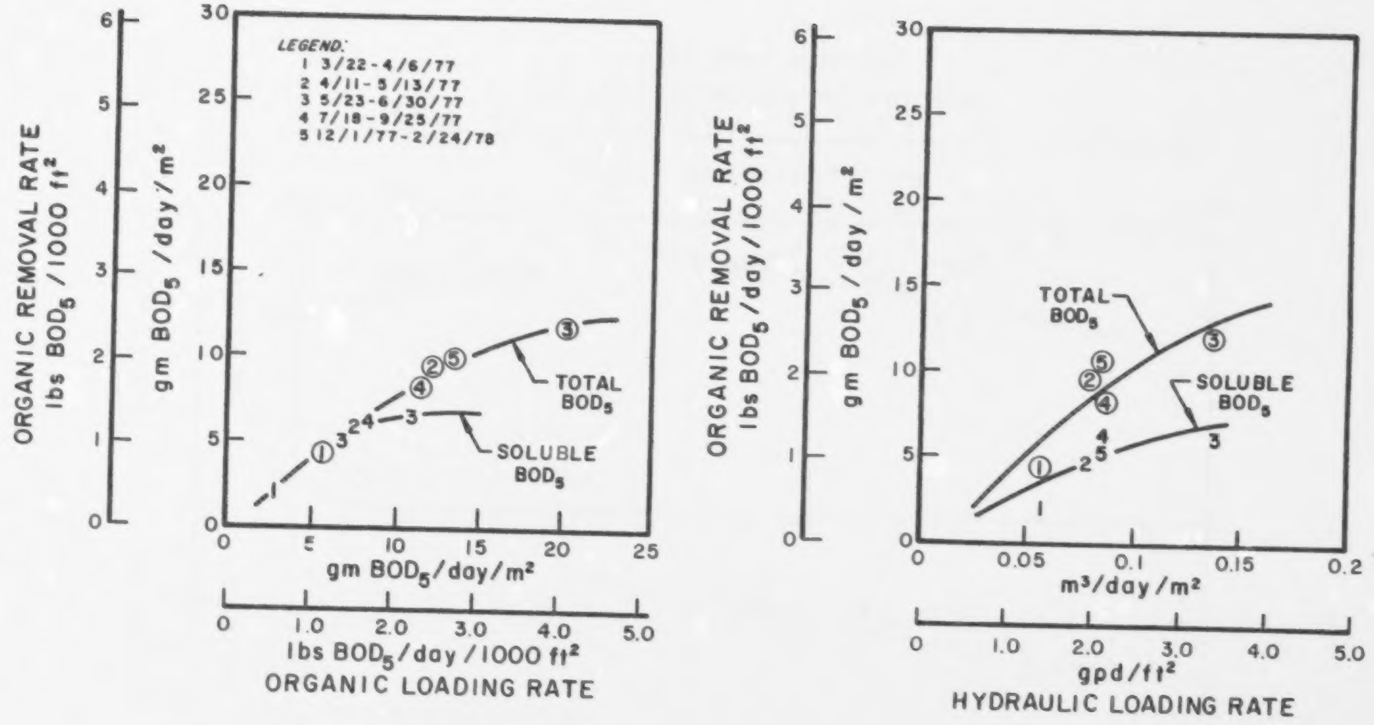


Figure 33. Correlation of organic and hydraulic loading rate to organic removal rate

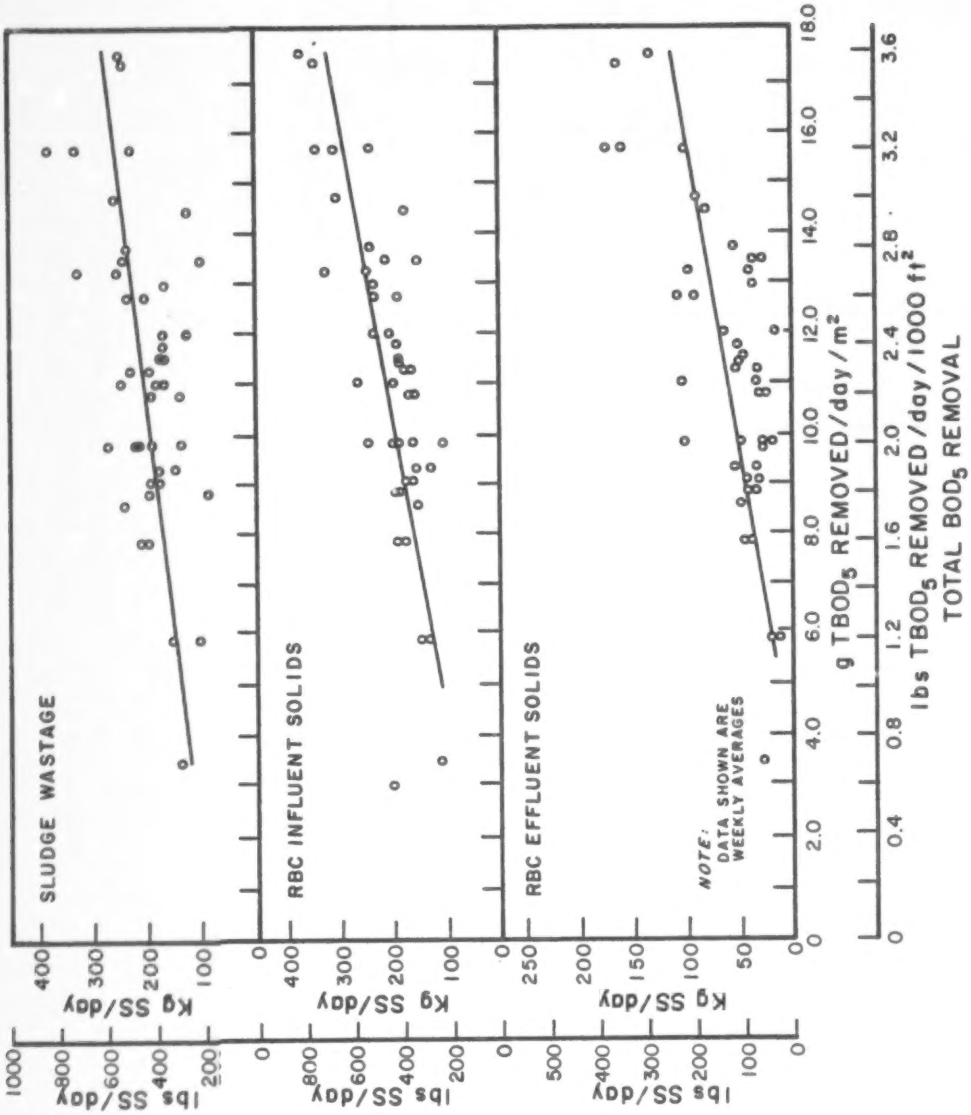


Figure 34. Influent, effluent and waste solids inventories

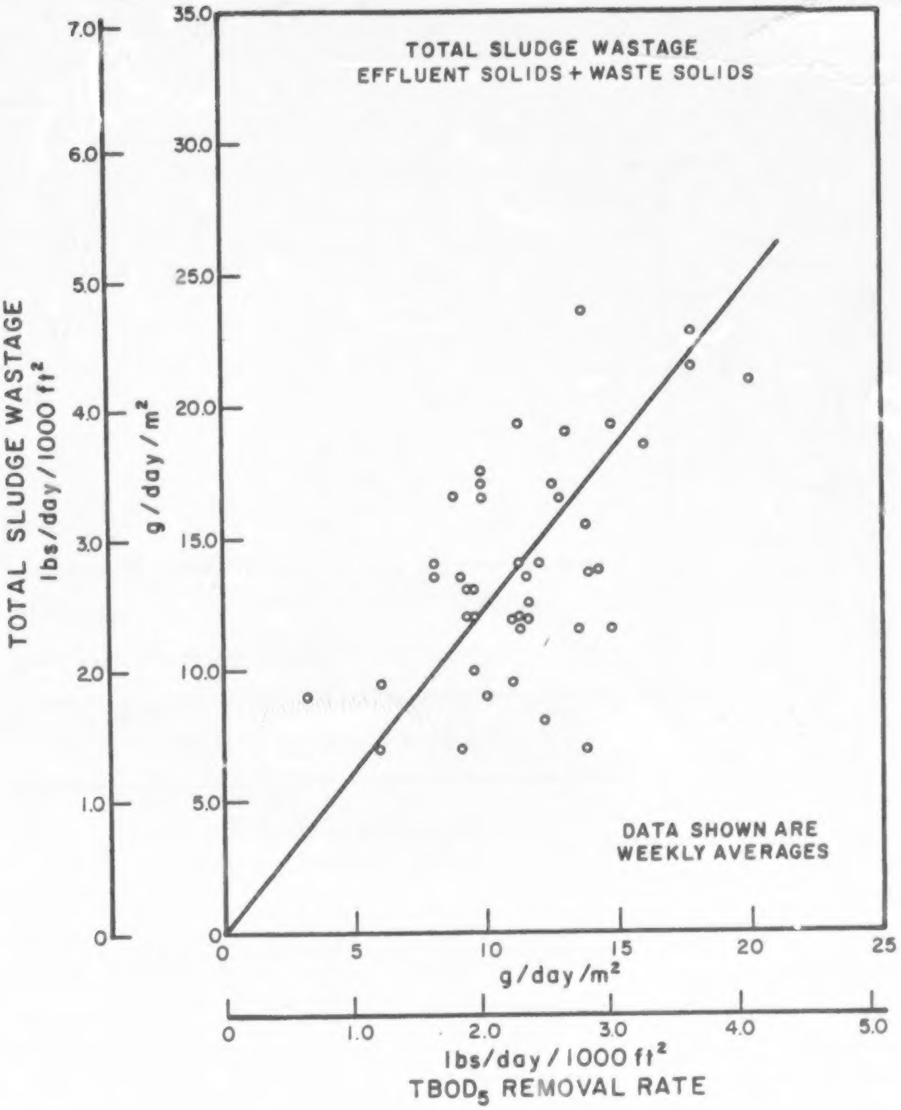


Figure 35. Correlation of total suspended solids wastage and $TBOD_5$ removal

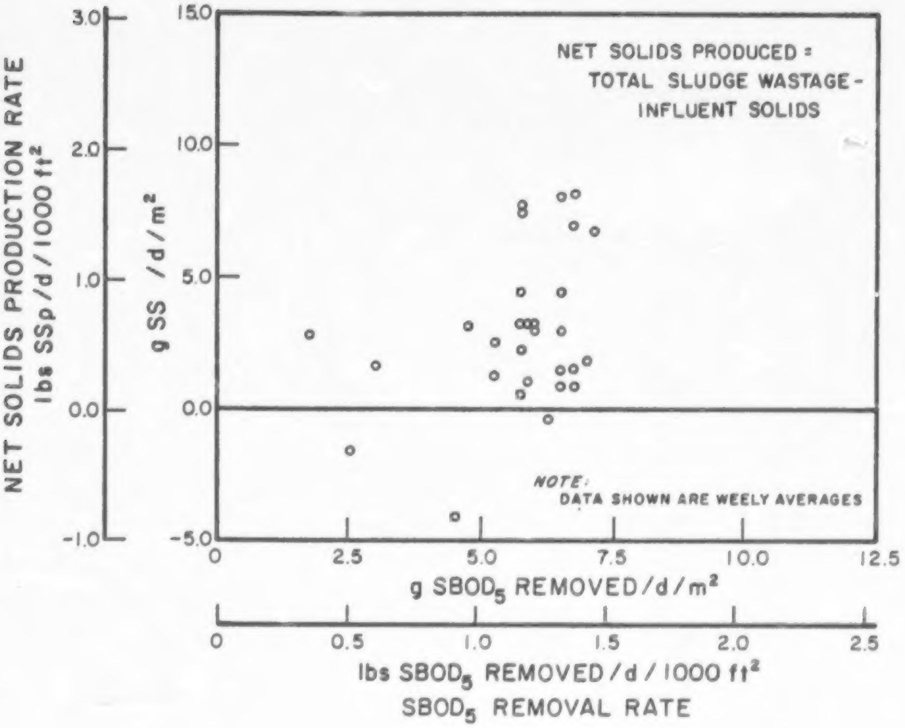


Figure 36. Correlation of net solids production to SBOD$_5$ removal rate

SECTION 7

ANALYSIS AND DISCUSSION - PROCESS DESIGN ALTERNATIVES EVALUATION

The extensive field study conducted at Edgewater, New Jersey, resulted in the collection of a large amount of data to describe the physical and biological performance of the RBC/Underflow Clarifier process. The data analysis and evaluation presented in Section 6 determined the concept of modifying primary tanks with RBC systems to be an effective treatment sequence, capable of accomplishing secondary treatment effluent requirements under reasonable operating conditions. This section projects the results of this analysis to the development of process design alternatives. The RBC kinetic model, calibrated with the Edgewater data, was utilized to develop design nomographs and to project the impact of variations in operating conditions. The surveys can facilitate the preliminary design for upgrading similar municipal wastewater primary treatment plants and are used in a subsequent section to develop a process design applicable to the Edgewater plant.

PRETREATMENT

Observations and data gathered in the study indicated a need for pretreatment to remove grit, trash, and floatables prior to the RBC system. Typically, 20 to 25 percent removals were accomplished in the pretreatment sector of the Edgewater system in addition to the removal of large fibrous materials on coarse screens. The influent TSS concentration to the RBC system averaged between 120 and 140 mg/l. Conservatively, the nominal overflow rates to accomplish this was estimated between 285 and 370 $m^3/d/m^2$ (7,000 to 9,000 gpd/ft^2) on average, with a peak rate of approximately 500 $m^3/d/m^2$ (12,300 gpd/ft^2).

Several alternatives may be available at a specific installation to provide pretreatment. If the plant is not at hydraulic capacity, the removal accomplished by the existing screens/grit chamber may prove adequate. If further treatment is required, this may be provided by incorporating high-rate gravity settling (as with Edgewater) and/or by the installation of sieves or screens. In the case of Edgewater, at the primary peak flow of 30,000 m^3/d (8 mgd), the use of one of the existing clarifiers to provide pretreatement would yield an overflow rate of 325 $m^3/d/m^2$ (8,000 gpd/ft^2), which is well within the recommended range.

ROTATING BIOLOGICAL CONTACTORS

RBC fixed film systems function primarily in the removal of soluble organic material, measurable as soluble BOD_5 and COD. Thus the design of the system is based on soluble organic loading and soluble effluent organic requirements. As shown on Figure 33, the rate of removal of $TBOD_5$ is relatively linear with the rate of $TBOD_5$ loading. The removal of soluble BOD_5 reaches a limiting rate, however, at the higher soluble (and total) BOD_5 loading rates to the system. These relationships suggest that the fraction of the $TBOD_5$ influent loading associated with solids will be removed from the system by clarification and these removals are related more to the hydraulic loading of the system. The soluble removals, however, are directly related to biofilm kinetics and the ability of the system to transfer sufficient oxygen.

The design sequence assumes, based on the above, that the secondary clarification sector will provide adequate solids removal efficiency and reduce TSS levels to within a desired range. The BOD_5 associated with these solids can be computed from measured BOD_5 to TSS correlations; from this the required effluent soluble BOD_5 can be determined. As an example, if the effluent solids are to average 25 mg/l, and the BOD_5:TSS correlation is $BOD_5 = 0.5\ TSS - 5$, the effluent BOD_5 associated with the solids is 7.5 mg/l. If a similar 25 mg/l criteria is set for average effluent BOD_5, the soluble fraction should not exceed 17.5 mg/l.

Design Nomographs

The design of a full-scale system can be facilitated through modeling techniques. Single stage design nomographs were developed on the basis of the kinetic model verifications discussed in Section 6. These design curves were developed from the system evaluation at Edgewater and as such should not be directly applied to the design of systems for treatment of different wastewaters. The appropriate kinetic parameters should be determined and new design nomographs developed for any particular application. The curves are based on an evaluation of a municipal wastewater system and may be useful in preliminary design applications and general process sizing for the treatment of similar wastewaters.

The design of an RBC system should maximize BOD removals in each stage by controlling the BOD loading on the media surface. Maximizing removals in each stage minimizes the total media surface area requirements, thereby minimizing the initial capital expenditure requirements. The design curves presented on Figure 37 utilize this design basis.

Figure 37 shows the relationship between the applied soluble BOD_5 loading and resulting removal rates. These curves were developed with the RBC model for a single stage by varying the waste strength, hydraulic loading, and waste loading on the media surface area. The curves are based on the effective, or wetted, surface area

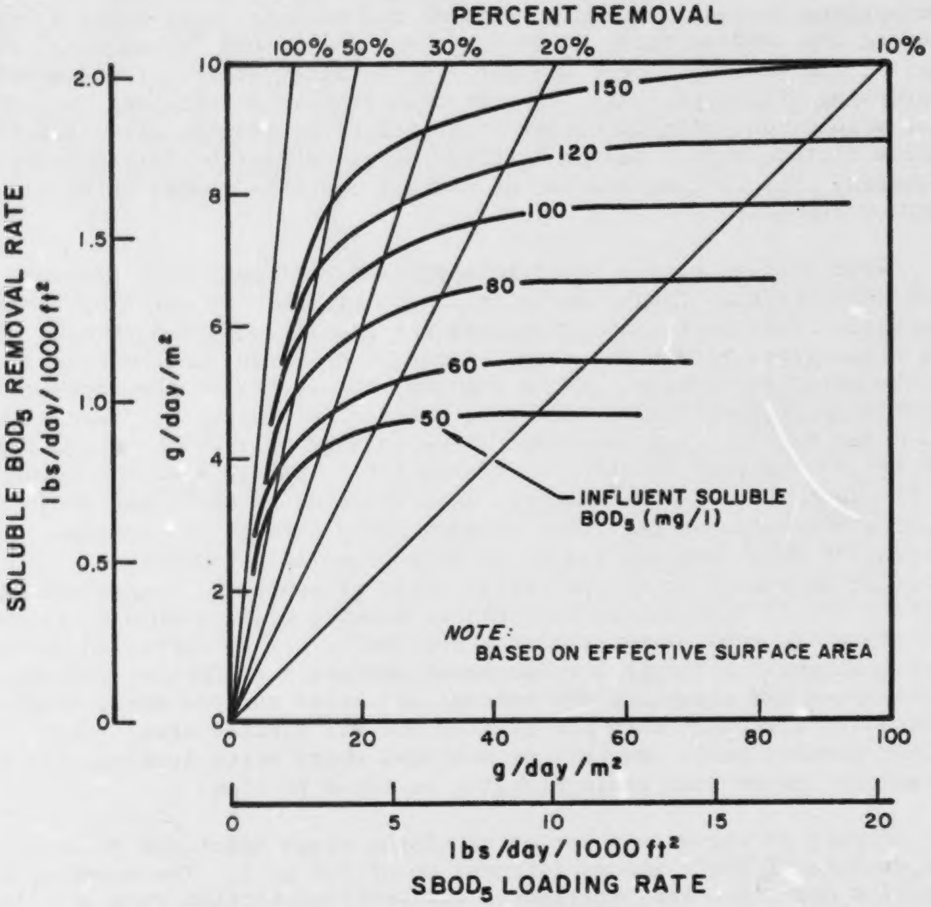


Figure 37. Process design curves relating BOD_5 loading rates to BOD_5 removal rates

of the media. For a given influent waste concentration, a point is reached where a further increase in the BOD_5 loading rate (or hydraulic loading) does not significantly increase BOD_5 removal. The design loading should not greatly exceed this point since the limit for removal by the available media has been reached. The percent removals begin dropping off significantly, resulting in an effluent concentration ultimately approaching the influent concentration. Effectively, the optimum design to maximize removal and minimize area would dictate keeping the loading equal in each stage. This means "pyramiding" the shafts; the greater number would be in the first stage, progressively decreasing with each stage. However, to achieve an effluent concentration without an infinite number of stages of decreasing size, practical limits dictate actual design loadings selected for the latter stages in a system. The initial stages, of course, could be loaded to obtain maximum removals.

When dealing with a specific application of upgrading primary treatment plants through the installation of RBC's in existing tanks, the waste loadings to each stage are not readily modified through varying stage sizes, since the stage sizes are dependent on the dimensions of the existing tankage. As an example, the stages at the Edgewater plant were separated with removable baffles, allowing the stage size and media surface area per stage to be changed only by their placement. The system remained constrained by the total surface area which could be fit to the available tankage. This resulted in decreased BOD_5 loading per media surface area progressively through the system. The decreasing BOD_5 loadings result in decreasing BOD_5 removals. In order to remain in the practical limit of number of stages and still achieve the 30 mg/l criteria, a higher density media with more discs and therefore greater surface area per shaft, can be installed in the latter stages. Although the increased surface area further reduces the BOD loading and resulting BOD removal per media surface area, total removals are increased with the greater overall surface area. The higher-density media can only be employed where waste loadings are sufficiently low so that media clogging is not a problem.

Figure 38 presents a series of single stage solutions based on a temperature of 20°C, and an influent DO of 0.0 mg/l. The reaction kinetics described and verified in the previous section were used in the development of the curves. At the appropriate influent soluble BOD_5 and hydraulic loading rate the resulting effluent soluble BOD_5 is determined. The predicted effluent $SBOD_5$ concentration from the first stage becomes the influent $SBOD_5$ to the second stage. The iterative use of the design curves allows the prediction of the effluent from a multi-stage RBC system.

To illustrate the use of Figure 38, consider the following example:

Influent Waste	$Q = 9,460\ m^3/d$ (2.5 mgd)
	$TBOD_5 = 200$ mg/l
	$SBOD_5 = 120$ mg/l

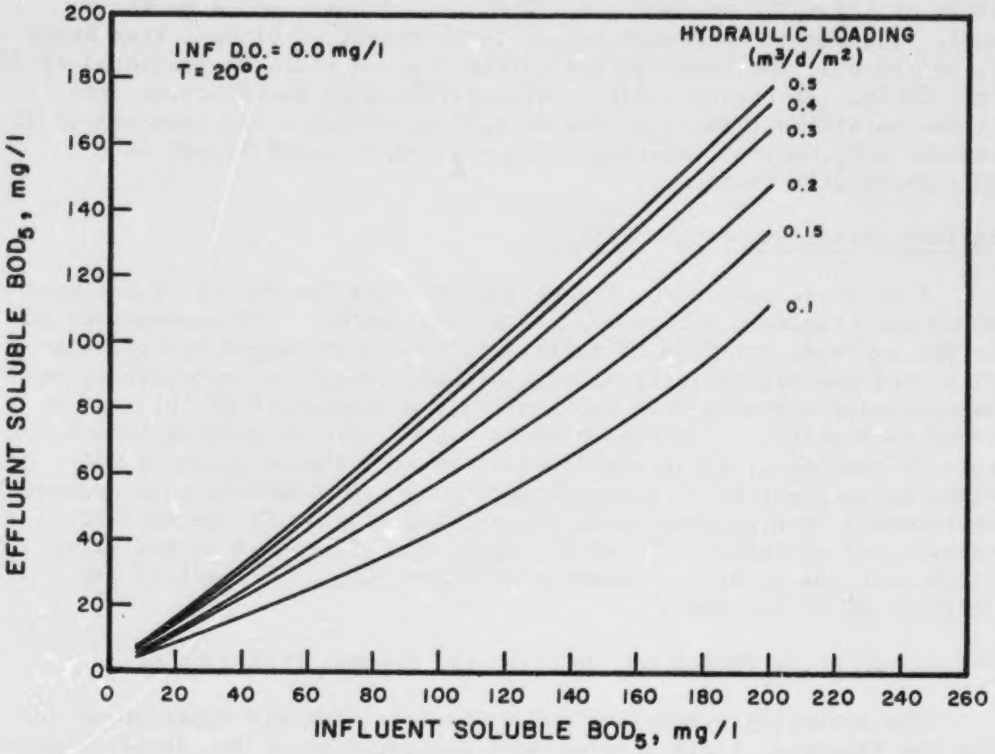


Figure 38. Single stage process design solutions relating effluent $SBOD_5$ to influent $SBOD_5$ and hydraulic loading

DO = 0.0 mg/l
Temperature = 20°C
Plant Capacity 6 rectangular tanks
Each Tank: 5 shafts
6,000 m^2 (64,500 ft^2)/shaft

The effective hydraulic loading rate to each stage would be 0.26 $m^3/d/m^2$ (6.4 gpd/ft^2). Entering Figure 38 at an influent $SBOD_5$ of 120 mg/l, the effluent $SBOD_5$ from Stage 1 would be 87 mg/l. The figure is re-entered at the influent of 87 mg/l from Stage 2, and so on. The final effluent from Stage 5 would be projected at 19 mg/l $SBOD_5$. If the secondary clarification zone is effective, and allows an effluent SS less than 30 mg/l on average, the criteria of 85 percent BOD_5 removal (effluent BOD_5 = 30 mg/l) would be met in this particular example.

Influent Dissolved Oxygen Effects

A third design curve, Figure 39, presents the effect of influent DO on the treatment efficiency of the RBC system. The presence of DO in the influent provides an additional source of oxygen for the biofilm, and may additionally allow a higher concentration gradient, enhancing mass transfer into the biofilm. A discussion of this may be found in Section 6. As indicated on Figure 39, the greater impact occurs at the higher substrate levels. At an influent $SBOD_5$ of 150 mg/l, an influent DO of 6.0 mg/l may allow approximately a 12 percent improvement in BOD_5 removed in the initial stage. In the earlier example, at an influent DO of 6.0 mg/l, the effluent from the first stage would be 83 mg/l, versus an effluent BOD_5 of 87 mg/l if the influent DO is 0.0 mg/l.

Comparison of Predicted and Observed RBC Removal Efficiencies

The operating conditions and equivalent removals experienced during the Edgewater field program were evaluated using the design Figures 38 and 39. Again, these were developed with the model, based on kinetic parameters determined during the study. Table 10 presents the observed average effluent $SBOD_5$ and the predicted effluent. The operating conditions for each experimental period are also summarized in Table 3.

TABLE 10. COMPARISON OF OBSERVED AND PREDICTED RBC EFFLUENTS

Study period	Observed eff. $SBOD_5$ (mg/l)	Predicted eff. $SBOD_5$ (mg/l)
Low loading (3/22-4/6/77)	10	7
Moderate loading (4/11-5/13/77)	22	21
High loading (5/23-6/30/77)	31	31
Warm temperature (7/18-9/25/77)	23	23
Cold temperature (12/1/77-2/24/78)	24	19

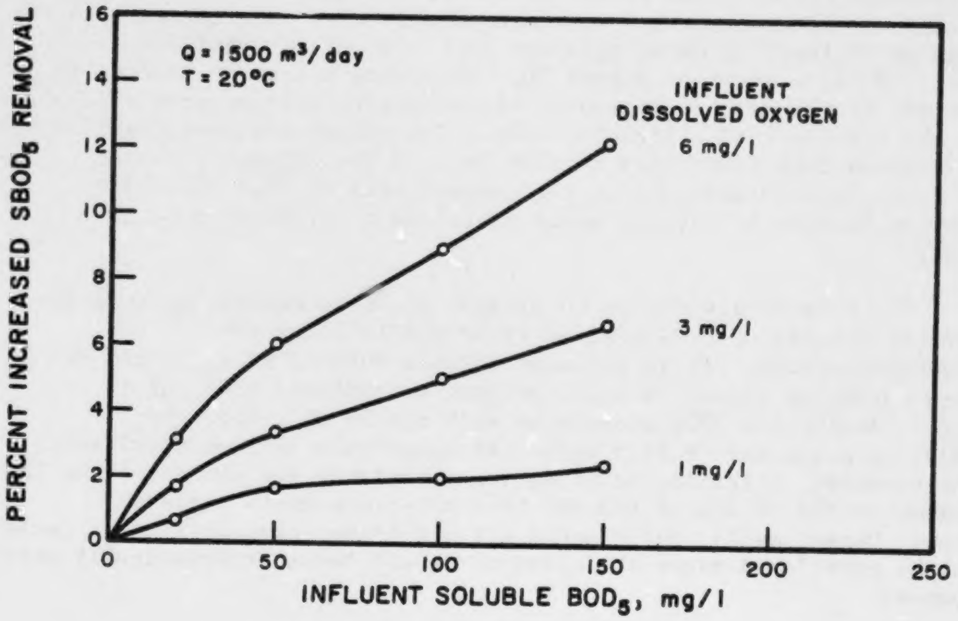


Figure 39. Single stage process design curves relating the effect of dissolved oxygen on $SBOD_5$ removals

As shown, the effluents predicted by the design curves closely approximate the observed data, especially under the range of loading conditions determined optimum for the system.

Secondary Clarification

The pilot study evaluation at Edgewater indicated that a limiting process condition in the operation of the system was the solids removal efficiency accomplished by the secondary clarification zone. The experimental data determined the maximum effective overflow rate to obtain an effluent SS of 30 mg/l was 26.5 $m^3/d/m^2$ (650 gpd/ ft^2). This is shown on Figure 30. Thus, the hydraulic loading to the RBC system may be limited by the effective surface area available in the secondary clarification zone. The tracer analyses (Section 6) determined this to be 54.6 m^2 (588 ft^2) in the Edgewater system (a 25 percent reduction from the nominal area of 72.8 m^2). The maximum flow to the system would therefore be 1,450 m^3/d (0.38 mgd).

The flow of 1,450 m^3/d (0.38 mgd) would be equivalent to a hydraulic loading of 0.07 $m^3/d/m^2$ (1.93 gpd/ft^2) for the Edgewater system. At an influent soluble BOD_5 of 90 mg/l, the design curves on Figure 38 would project an effluent $SBOD_5$ of 19 mg/l. Adding the BOD_5 associated with the 30 mg/l TSS, the $TBOD_5$ is projected at 26.5 mg/l. Although this will meet criteria, the secondary clarifier is effectively limiting the design of the RBC system to the 18,270 m^2 (43,000 ft^2) effective media surface area. Denser media, which would allow a higher organic loading could not be considered since the clarifier would become hydraulically overloaded.

To maximize the organic loading to the RBC sector and minimize the RBC surface area requirements, consideration must be given to the design of the underflow clarifier system to accomplish efficient solids capture. This may involve provision of additional secondary clarifiers, the use of chemical addition to improve the efficiency of the existing underflow clarifiers, or the use of rapid sand filters as a final treatment step.

Other Process Considerations

pH --

As with any biological system, effective pH control in the range of 6 to 8 is a necessity. Extreme pH drops at Edgewater during August and September 1977 caused sloughing of the biofilm and loss of treatment efficiency for a period of days. Depending on the type of system, especially in highly industrialized areas, pre-neutralization facilities may be required.

Pre-aeration --

Due to the nature of the system (decreasing loading with progressive staging) the provision of pre-aeration to the RBC/Underflow Clarifier process would probably not be effective in improving treatment efficiency.

A simulation was run to demonstrate the effect of pre-aeration during summer conditions. Table 11 presents soluble BOD_5 and DO concentrations in each stage under moderate loading conditions.

TABLE 11. EVALUATION OF PRE-AERATION

Flow	1,550 m^3/day (0.409 mgd)		
Hydraulic loading	0.085 $m^3/d/m^2$ (2.08 gpd/ft^2)		
Soluble BOD_5 loading	8.26 g $SBOD_5/d/m^2$ (1.69 lbs $SBOD_5/d/1,000\ ft^2$)		
Temperature	26.1°C		
O_2 saturation	7.9 mg/l		
Influent soluble BOD_5	100 mg/l		
Influent dissolved oxygen (mg/l)		0.0	6.0
Soluble BOD_5 stage 1		78	75
2		58	56
3		43	41
4		27	26
Dissolved oxygen stage 1		0.6	2.2
2		0.7	1.2
3		1.3	1.5
4		2.0	2.1

As shown, the impact of pre-aeration is relatively minimal on a multistage system. The systems, beyond the first stage, become increasingly similar in dissolved oxygen levels with each stage. Thus, BOD_5 removals are relatively the same, except in the first stage which experienced the greater O_2 differential.

Filamentous Organisms

The recurring appearances of filamentous organisms did not appear to affect the treatment efficiency of the Edgewater system. If, however, under certain circumstances they create a problem, the use of hydrogen peroxide appeared to an effective remedy. Also, in the specific case of beggiatoa, the addition of an alternate oxygen source (other than sulfate), such as nitrate, or pre-aeration, may prove to be an effective preventive during the warm summer months.

Staging Baffles

Baffles effectively stage the RBC system into a series of completely mixed tanks. Their consideration in process design should be to the extent that each tank, as defined by the baffles, should be close to completely mixed. At Edgewater, a stage with one or two shafts was shown to be completely mixed. It is probable that a stage with three shafts would also be shown completely mixed.

Baffling will also create higher velocities along the intermediate floor and minimize solids accumulation. In line with this, placement of baffles beyond two shafts may not be appropriate. The underflow clearance is also an important consideration in the installation of the baffles. A clearance of 5 cm (2 in) was found to be effective at Edgewater, inducing sufficient wastewater velocity to keep the intermediate floor free of significant sludge deposits.

SECTION 8

PROCESS DESIGN EVALUATION OF EDGEWATER SYSTEM

The following example is presented to demonstrate the use of the design curves and to further discuss process considerations relating to the RBC/Underflow Clarifier system. Since the curves are based on the experimental program at Edgewater, the example describes the process requirements to upgrade the existing Edgewater facility to secondary treatment capabilities, based on the present-day waste characterization. Subsequent sections (9 and 10) discuss plant design considerations, and develop costs related to design of the Edgewater system.

WASTE CHARACTERIZATION - PRESENT CONDITIONS

Because Edgewater is a combined system, the variations in flow and pollutant strength do not coincide, i.e., at higher storm flows the waste strength becomes highly diluted. For this reason, the loadings to the system do not show the high variations exhibited by the flow and concentrations. Peak organic loading conditions are not a direct multiplication of peak flow and peak concentrations, since it is assumed they would not occur simultaneously. Actual design of the RBC system is based on the average loadings to the system, while the clarifier design is considered on the basis of peak flows.

The waste characterization summarized on Table 12 is based on cumulative normal distributions of the data obtained during the experimental program. Daily average is the mean occurrence, while the peak monthly average is taken as the 91.5 percent occurrence. The 98 percent occurrence represents the peak 7-day average.

TABLE 12. EDGEWATER WASTE CHARACTERIZATION: PRESENT CONDITIONS

	Daily average	Peak monthly average	Peak 7-day average
Flow, m^3/d (mgd)	9,800 (2.6)	13,600 (3.6)	15,900 (4.2)
$TBOD_5$, mg/l	145	215	250
$SBOD_5$, mg/l	90	130	150
TSS, mg/l	170	260	300
$TBOD_5$ loading, kg $TBOD_5$/d (lbs/d)	1,620 (3,570)	2,120 (4,670)	2,490 (5,480)
$SBOD_5$ loading, kg $SBOD_5$/day (lbs/day)	855 (1,885)	1,320 (2,900)	1,550 (3,400)
TSS loading, kg TSS/d (lbs/d)	1,620 (3,570)	2,630 (5,790)	3,130 (6,900)
Temperature	11°C (winter) to 26°C (summer)		
Influent DO (mg/l)	5.0 (winter) to 1.0 (summer)		

EFFLUENT REQUIREMENTS

The Federal standards and requirements based on the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) call for monthly average BOD_5 and SS concentrations less than or equal to 30 mg/l, or a percent removal equal to or greater than 85 percent, whichever allows the greater treatment. Additionally, weekly average BOD_5 and SS concentrations must not exceed 45 mg/l. Effluent limitations based on percent removals are more stringent for wastes having a low influent BOD_5, as is the case for Edgewater. The effluent criteria which would apply to Edgewater under the influent waste characterization described in Table 12 are presented on Table 13.

TABLE 13. ESTIMATE OF EFFLUENT CRITERIA
(Based on Waste Characterization Shown on Table 12)

	Daily average	Peak monthly average	Peak 7-day average
Total BOD_5	22	30	45
Total SS	25	30	45
Soluble BOD_5	14	20	27

The daily average BOD_5 and TSS are limited by the 85 percent removal criteria, while the concentration limitations govern the allowable peak monthly and peak 7-day BOD_5 and TSS levels. An equivalent soluble BOD_5 is shown; it was estimated by subtracting from the total the BOD_5 associated with the solids (Table 7).

PRETREATMENT

The results of the Edgewater study indicated that the influent to the RBC sector should not exceed 120 to 140 mg/l suspended solids. A single primary clarifier at Edgewater would be used to provide high rate primary treatment for the entire plant flow. The monthly average overflow rate would be 170 $m^3/d/m^2$ (3,600 gpd/ft^2), with a peak storm flow overflow rate of 340 $m^3/d/m^2$ (7,200 gpd/ft^2). Figure 12 shows that within this range, 20 to 25 percent TSS removals can be expected. No removals of BOD_5 are assumed through this pretreatment step.

SECONDARY CLARIFICATION

Figure 30 presents the relationship of effluent TSS as a function of effective overflow rate developed from the experimental program. The designs projected on Table 14 are based on this figure.

TABLE 14. UNDERFLOW CLARIFIER PROCESS DESIGN REQUIREMENTS AT EDGEWATER

	Daily average	Peak monthly average	Peak 7-day average
Required effluent SS criteria (1), mg/l	25	30	45
Required effective overflow rate (2), $m^3/d/m^2$ (gpd/ft^2)	23.5 (570)	26.5 (650)	35 (860)
Actual flow (3), m^3/d (mdg)	9,800 (2.6)	13,600 (3.6)	15,900 (4.2)
Required effective intermediate floor area, m^2 (ft^2)	420 (4,560)	510 (5,540)	450 (4,890)

(1) From Table 13.
(2) From Figure 30.
(3) From Table 12.

The controlling condition is the peak monthly average, whereby a total effective surface area of 510 m^2 (5,540 ft^2) is required. The effective surface area in the Edgewater system was estimated at 54.6 m^2 (588 ft^2) per tank. With four available tanks, the above design would indicate an additional 290 m^2 (3,120 ft^2) of effective surface area is required.

The test module used at Edgewater could be redesigned to provide a greater surface area. The intermediate floor can be extended to a total length of 19.8 m (65 ft), to allow a clearance of 1.5 m (5 ft) for the turnaround and scraper mechanism. The false floor area in this case would be 86 m^2 (930 ft^2). Assuming 75 percent effective use of the available surface area, the effective surface area would be 64.5 m^2 (700 ft^2), and the additional surface area requirement would be reduced to 250 m^2 (2,670 ft^2). Additional improvements in the hydraulics of the turnaround/clarifier sector to allow 100 percent utilization of the clarifier would reduce the additional area requirement to 165 m^2 (1,770 ft^2). Note that these assumptions are based on an evaluation of the Edgewater underflow clarifier, with a depth of 4.5 ft. Deeper clarifiers may exhibit different characteristics.

RBC ORGANIC REMOVAL

Four primary clarifiers would be available for conversion to the RBC system at the Edgewater plant. Maximum use of the tankage would allow four 4.1 m (13.5 ft) shafts (3.65 m diameter) per tank. High-density media would be installed in all but the first shaft in each tank and conventional density media would be installed in the first stage. Each shaft would be 0.46 m (30 in) above the water surface.

Using Figures 38 and 39, the effluent resulting from this configuration of the four-tank system would be computed as shown on Table 15. The flow and hydraulic loading are derived from the stated soluble BOD_5 loading and concentrations. As shown, the projected effluent $SBOD_5$ is substantially higher than the required $SBOD_5$.

Figure 40 presents the solutions for a varying number of tanks based on the design curves shown on Figures 38 and 39. For the particular application described above, the soluble effluent BOD_5 criteria under peak monthly conditions would be met with a total of nine tanks, each with four RBC shafts and a total effective media surface area of 22,600 m^2 (243,000 ft^2) per tank. The total nominal media surface area per tank would be 27,300 m^2 (294,300 ft^2).

Assuming extension of the intermediate floor to provide an effective surface area of 64.6 m^2 (695 ft^2) per tank, nine tanks would provide a total surface area (effective) of 580 m^2 (6,250 ft^2). This would be in line with the required secondary clarifier surface area under peak monthly flow conditions as shown on Table 14.

SUMMARY OF PROCESS DESIGN EVALUATION

The process design of both the underflow clarifier and the RBC sectors was controlled by the peak monthly average condition at Edgewater. The design is summarized on Table 16. A total of ten tanks would thus be necessary at Edgewater, one for high-rate pretreatment, and the remaining nine modified or newly constructed as RBC/Underflow Clarifier processes.

The total primary tankage surface area presently at Edgewater is 465 m^2 (5,000 ft^2). This is equivalent, at an average flow of 9,500 m^3/day (2.5 mgd) to a primary overflow rate of 20.4 $m^3/d/m^2$ (500 gpd/ft^2). By doubling the tankage, the equivalent overflow rate is reduced to 10.2 $m^3/d/m^2$ (250 gpd/ft^2). Such an analogy becomes useful for extrapolation of the Edgewater results to a similar primary treatment plant. If a plant is designed for an average primary overflow rate of 30.6 $m^3/d/m^2$ (750 gpd/ft^2) the plant tankage would need to be tripled to accommodate sufficient RBC media surface area.

TABLE 15. PRELIMINARY DESIGN OF EDGEWATER MODIFICATION USING EXISTING TANKAGE(1)

	Daily Average	Peak Monthly Average	Peak 7-Day Average
Influent Flow(2), m^3/day (mgd)	9,460 (2.5)	10,200 (2.7)	10,200 (2.7)
Hydraulic Loading(3) $m^3/d/m^2$ (gpd/ft^2)			
Overall	0.1 (2.57)	0.11 (2.77)	0.11 (2.77)
Stage 1	0.59 (14.5)	0.64 (15.7)	0.64 (15.7)
Stages 2, 3 & 4	0.38 (9.4)	0.41 (10.1)	0.41 (10.1)
TBOD$_5$ Loading Rate, $g/d/m^2$ (lbs/d/1000 ft^2)	15.2 (3.1)	23.5 4.8)	27.5 (5.6)
SBOD$_5$ Loading Rate, $g/d/m^2$ (lbs/d/1000 ft^2)	9.5 (1.9)	14.6 3.0)	17.1 (3.5)
Influent Soluble BOD$_5$ (mg/l)	90	130	150
Temperature (C)	20	20	20
Dissolved Oxygen (mg/l)	3.0	3.0	3.0
Soluble BOD$_5$ (mg/l)			
Stage 1	77	114	134
Stage 2	59	92	109
Stage 3	45	73	87
Stage 4	33	59	69
Soluble BOD$_5$ Requirement(4)	14	20	27

(1) One primary clarifier is converted to high rate system. Remaining four are used for RBC conversion.

(2) Computed from Organic Loading and Concentrations on Table 12.

(3) Effective surface area Stage 1 = 4,000 m^2 (43,000 ft^2); Stages 2, 3 and 4 = 5,200 m^2 (67,000 ft^2); Total Surface Area/Tank = 22,600 m^2 (244,000 ft^2).

(4) From Table 13.

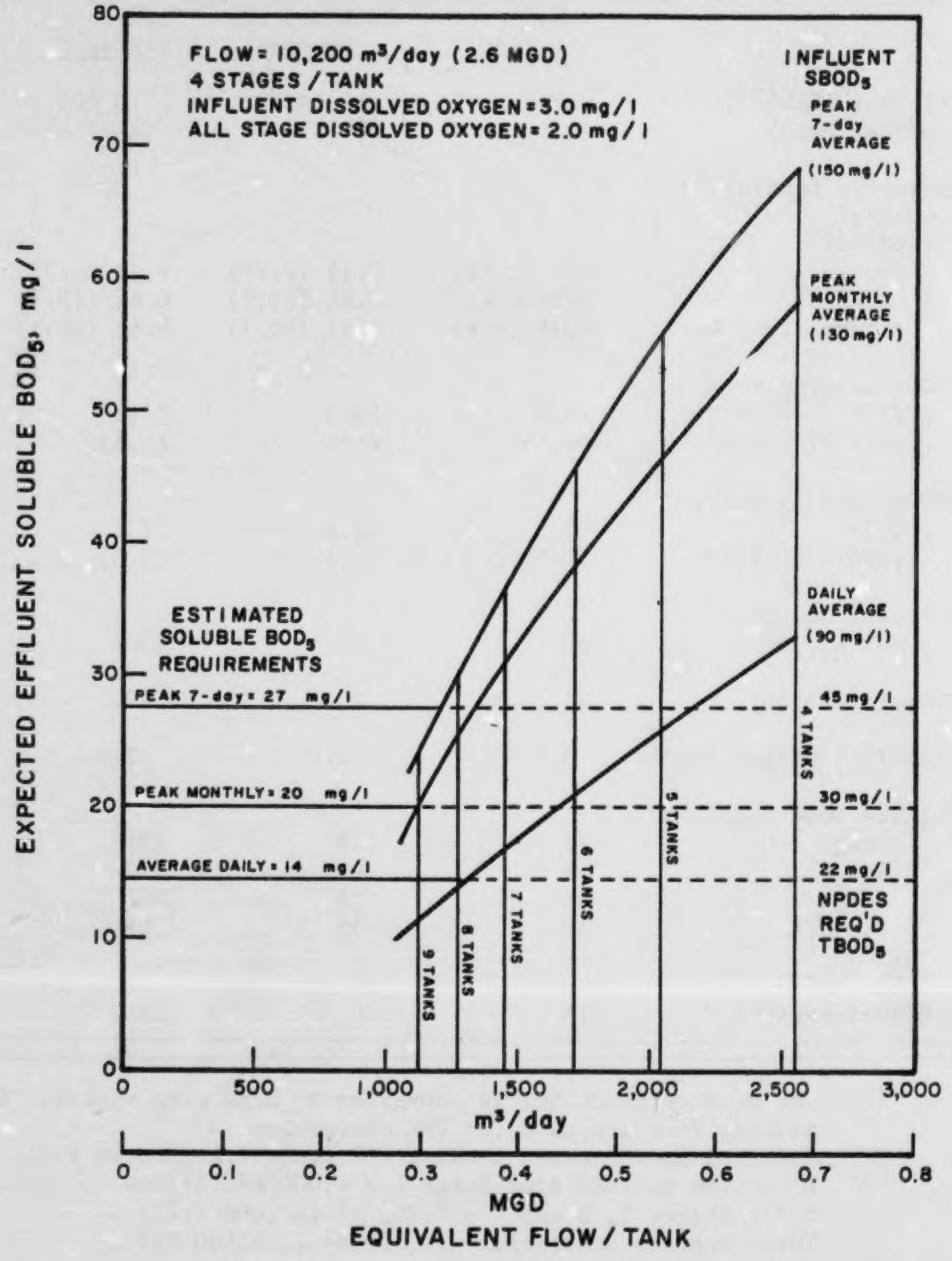


Figure 40. Process design at Edgewater

TABLE 16. PROCESS DESIGN SUMMARY AT EDGEWATER UNDER PRESENT CONDITIONS

Process conditions:	
Peak monthly average	
TBOD$_5$ loading	2,120 kg/day (4,670 lbs/day)
SBOD$_5$ loading	1,320 kg/day (2,900 lbs/day)
SBOD$_5$	130 mg/l
Temperature	20^{o}C
Flow (based on loading)	10,200 m^3/day (2.7 mgd)
Influent DO	3.0 mg/l
Flow to clarifier	13,600 m^3/day (3.6 mgd)
Process design parameters:	
TBOD$_5$ loading rate	10.4 g/d/m^2 (2.1 lb/d/1,000 ft^2)
SBOD$_5$ loading rate	6.5 g/d/m^2 (effective) (1.3 lb/d/1,000 ft^2)
Equivalent hydraulic loading rate	0.05 m^3/d/m^2 (1.2 gpd/ft^2)
Clarifier overflow rate at peak Monthly Hydraulic Flow	23.5 m^3/d/m^2
Process design (using existing Edgewater tank design):	
Total nominal RBC media Surface Area	246,000 m^2 (2.65 x 10^6 ft^2)
Total effective RBC media surface area	203,400 m^2 (2.2 x 10^6 ft^2)
Shafts/tank	4
Total RBC tanks	9
Total intermediate floor surface area	580 m^2 (6,200 ft^2)

PROCESS DESIGN MODIFICATIONS

Specific improvements can be made in the design of the Edgewater plant which may result in a reduction of total required tankage. Two methods suggested are aeration to DO levels of 5.0 mg/l throughout the system, and the use of chemical treatment to improve solids capture efficiency.

Aeration can be provided by a supplemental air supply. Although not evaluated directly during the Edgewater study, the potential impact of interstage aeration was simulated by the use of the design Figures 38 and 39. The results were superimposed over results of the initial Edgewater design example (Figure 40) and are displayed on Figure 41. The simulation indicated that provision of interstage aeration alone did not significantly improve the design.

Tests were conducted during the study which indicated that the addition of $FeCl_3$ to the four stage mixed liquor would significantly enhance the settleability of the solids. The bench scale tests indicated, however, that it was necessary to provide a sufficient period of agitated contact between the waste and coagulant prior to the clarification zone. The results of these studies (Figure 31) showed that within the clarifier operating range of 20 to 25 $m^3/d/m^2$ (overflow rate), chemical addition (20 mg/l $FeCl_3$) would allow an effluent TSS of 15 to 20 mg/l.

At Edgewater, the rapid mix zone would need to be provided to assure efficient chemical treatment. Alternatives may involve injecting the $FeCl_3$ solution directly above the air header if supplemental air is being provided or by installing a separate baffled stage on the extended intermediate floor, with adequate mechanical mixing.

If the effluent solids are maintained at 15 mg/l, soluble BOD_5 effluent requirements change significantly. These are shown on Figure 41. The BOD_5 associated with the 15 mg/l TSS is assumed to be 3 mg/l (Table 7). Thus the daily, peak monthly, and peak 7-day average $SBOD_5$ requirements become 19, 27 and 42 mg/l, respectively. As shown on Figure 41, the peak monthly condition again governs, but the tankage requirement for the RBC system is now reduced to seven tanks (vs. nine in the initial design), assuming provision of supplemental air.

The use of seven tanks would allow an effective clarifier surface area of 450 m^2 (4,850 ft^2). At the peak monthly flow of 13,600 m^3/d (3.6 mgd) the effective clarifier overflow rate would be 30 $m^3/d/m^2$ (740 gpd/ft^2). Figure 31 indicates that with adequate chemical treatment, effluent TSS criteria will be met.

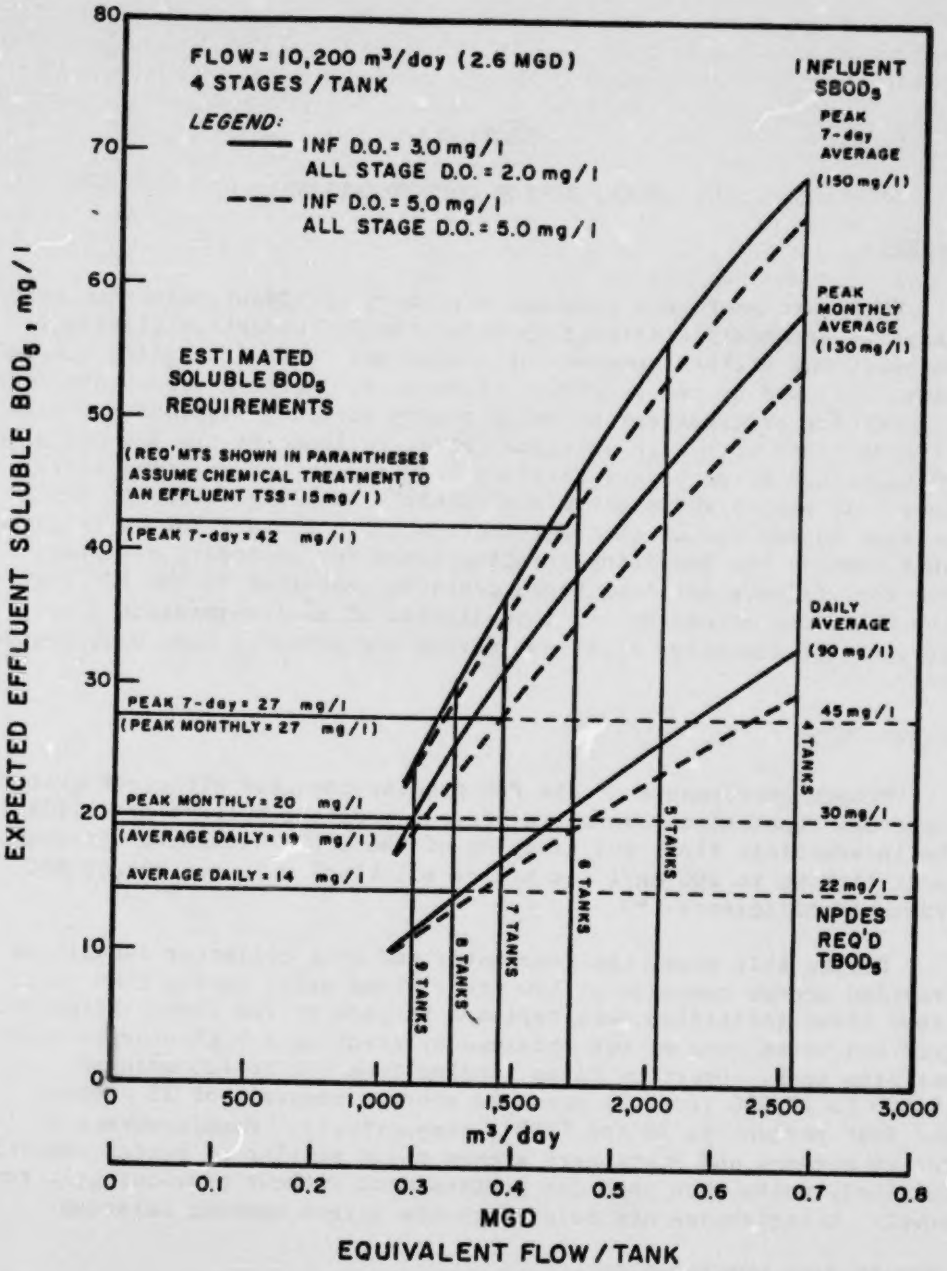


Figure 41. Process design at Edgewater with aeration and chemical treatment

SECTION 9

PLANT DESIGN CONSIDERATIONS

GENERAL

There are many ways in which a primary treatment plant may be upgraded to secondary treatment by using the RBC/Underflow Clarifier process. One of them consists of adding new tanks containing the RBC units, followed by new secondary clarifiers. Another scheme consists of providing pretreatment by using rotary screens, stationary sieves or settling tanks with high overflow rates, followed by the RBC units in new tanks and by secondary settling provided in the existing clarifiers. In plants where there are multiple settling tanks, it may be possible to use one of them for pretreatment, install RBC units in new tanks and use the remaining existing tanks for secondary settling. Some deep primary settling tanks could be converted to the RBC/Underflow Clarifier scheme by the installation of an intermediate floor. This section discusses this last method and presents some examples and costs.

PRETREATMENT

Proper performance of the RBC process requires efficient grit, trash and floatables removal to prevent possible buildup of solids on the intermediate floor and clogging of the media openings. Grease concentration up to 200 mg/l (as hexane solubles) will not reduce RBC treatment efficiency.(4)

During this study the comminutor and grit collector facilities provided proper removals at low plant flows only; during high plant flows these facilities were bypassed by part of the flow. Efficient grit and trash removal was obtained by creating a high-overflow-rate settling tank. Overflow rates ranging from 204 to 725 $m^3/d/m^2$ (5,000 to 18,000 gpd/ft^2) produced average removals of 25 percent and four percent in SS and $TBOD_5$, respectively. Manufacturers of rotary screens and stationary sieves claim similar or better removals for their units when used for pretreatment without previous grit removal. Efficiencies are related to the screen opening selected.

PRIMARY TANK MODIFICATIONS

Installation of RBC units in existing primary settling tanks required several modifications to the tanks. Figures 3 and 4 present a cross-section of the primary settling tanks before and after the installation of RBC units. Modifications to existing tanks may differ completely from those required in Edgewater, but in general will consist of:

(1) Sludge Collecting Mechanism. The division of the tank created by the intermediate floor requires that the chain sludge collectors operate in the sedimentation zone with the flights return located at about 0.90 m (3 ft) above the tank floor. Other types of sludge collectors such as the travelling bridge and the rotary collectors must be completely removed and replaced by chain collectors. Cross-collectors may or may not have to be removed, depending on the dimensions of the tanks and the space required by the RBC units.

(2) Scum Collection Equipment. Scum-collecting arms, troughs, revolving skimming pipes, etc., must be removed. Scum removal must be accomplished by pretreatment facilities.

(3) Effluent Collection Launders. Some tanks are provided with launders, troughs or weirs that project toward the tank or are installed in the periphery of the tanks. This equipment must be removed.

(4) Cross-Tank Beams. In general, it is necessary to remove the cross-tank beams and replace them with new beams. Cross-beams usually do not have the separation required for installation of the RBC units, and generally do not have sufficient width to allow proper installation of covers and baffles leaving adequate separation between covers. New cross-beams are usually installed in pairs to allow the installation of baffles between them.

(5) Intermediate Floor. An intermediate floor must be installed to separate the two zones of the tank. The intermediate floor must be adequately supported, since the sludge-collecting mechanism may require service from time to time. The intermediate floor must be installed so as not to allow intermixing or short-circuiting of the sewage.

(6) Sidewalls. When multiple tanks are to be upgraded by the installation of RBC units, it may be necessary to change the design of the partition walls in order to provide adequate space for the support of bearings and motors. Interior cantilever walls (T-shape) are not recommended, since they provide spaces that may create short-circuiting. Figure 46 illustrates this problem. In tanks with multiple bays, it may be necessary to separate the flow streams by separating the bays with complete sidewalls. This may, in some cases, require relocation of interior columns, which represents a complete redesign of the tanks.

(7) Baffles. Interstage baffles between adjacent shafts must be installed. Since there are periods in which it may be desir-

able to remove baffles between two stages, it is important that these baffles be easily removed. Normally, the baffles should be installed to provide underflow. Installation of baffles providing overflow between stages requires the installation of fillets to eliminate dead zones where sludge may accumulate. If built from concrete, these fillets will represent a heavy weight to be supported in addition to the intermediate floor. These two types of arrangements are shown on Figure 42.

(8) Rearrangement of Influent and Effluent Channels and Weirs. As can be seen in Figure 4, the influent and effluent channels are located in the same side of the tank. This requires changes in the influent line and installation of proper channels and weirs. When upgrading very long tanks it may be necessary to divide the tank(s) into two or three sections with individual RBC units. This scheme requires installation of intermediate influent and effluent channels.

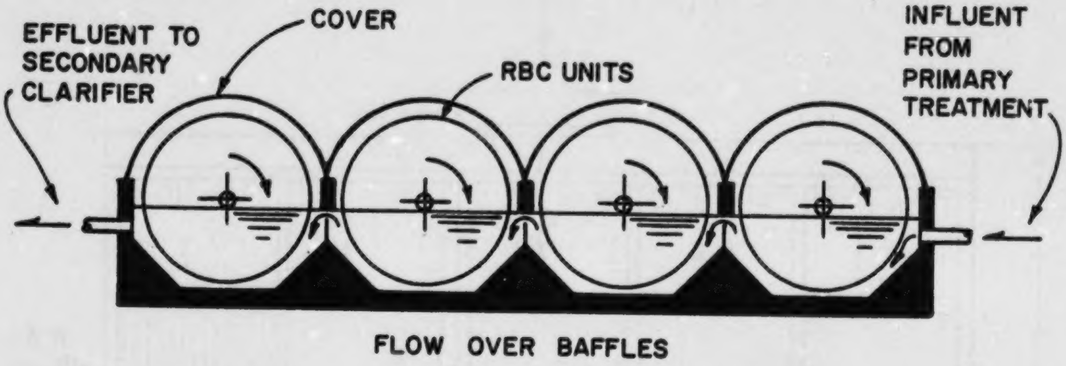
(9) Sludge Hopper. Existing tanks with rotary or travelling bridge sludge collectors require the installation of sludge hoppers for the proper sludge removal. Tanks with concave bottoms require addition of a flat bottom for proper operation of the chain-type sludge collectors.

TYPICAL LAYOUTS

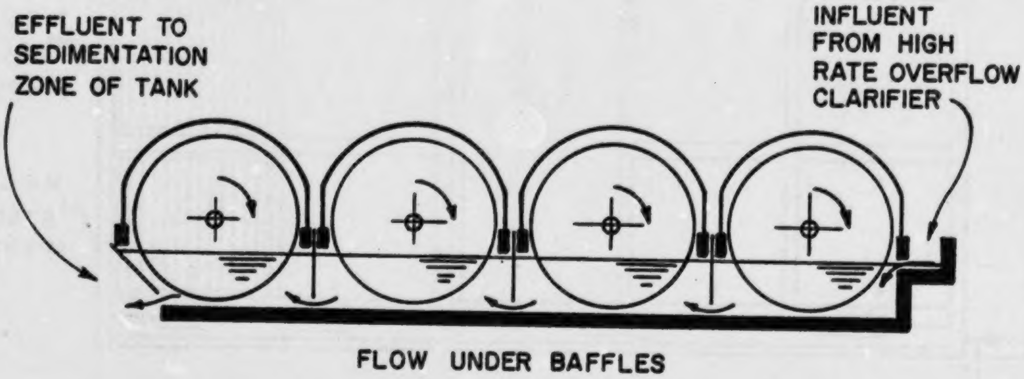
There is no "typical" primary treatment plant, since each plant has different configurations and dimensions. Accordingly, the layouts herein presented should be considered as representative examples. The proper capacity in each case should be determined by the hydraulic and organic loads imposed by a particular waste. Costs associated with each application will determine the economics of the system.

Example 1 - Small Plant with Multiple Tanks. Figures 43 and 44 present one possible layout to upgrade the Edgewater and similar primary treatment plants. Of the five primary settling tanks, the center tank is kept as a high-rate primary settling tank. The four remaining tanks are provided with RBC units. In order to reduce construction work on the partition walls as much as possible, the motors are located at the left side of the shafts in one tank and at the right side in the adjacent tank, and the covers designed to enclose two shafts instead of individual units. In this particular case, the wall between Tanks No. 3 and 4 is a double wall which provides enough space for the motor. The wall between Tanks No. 2 and 3 requires a beam with a cantilever to support the motor. Installation of RBC units in Tank No. 3 would have been impractical, as a consequence of the clearances required between motors, which substantially reduce the shaft length for this tank. In those cases where the strength of the sewage requires an RBC area greater than can be accommodated with this layout, additional tanks may be provided if land is available.

Example 2 - Small Plant with Two Tanks. Figure 45(a) presents a layout

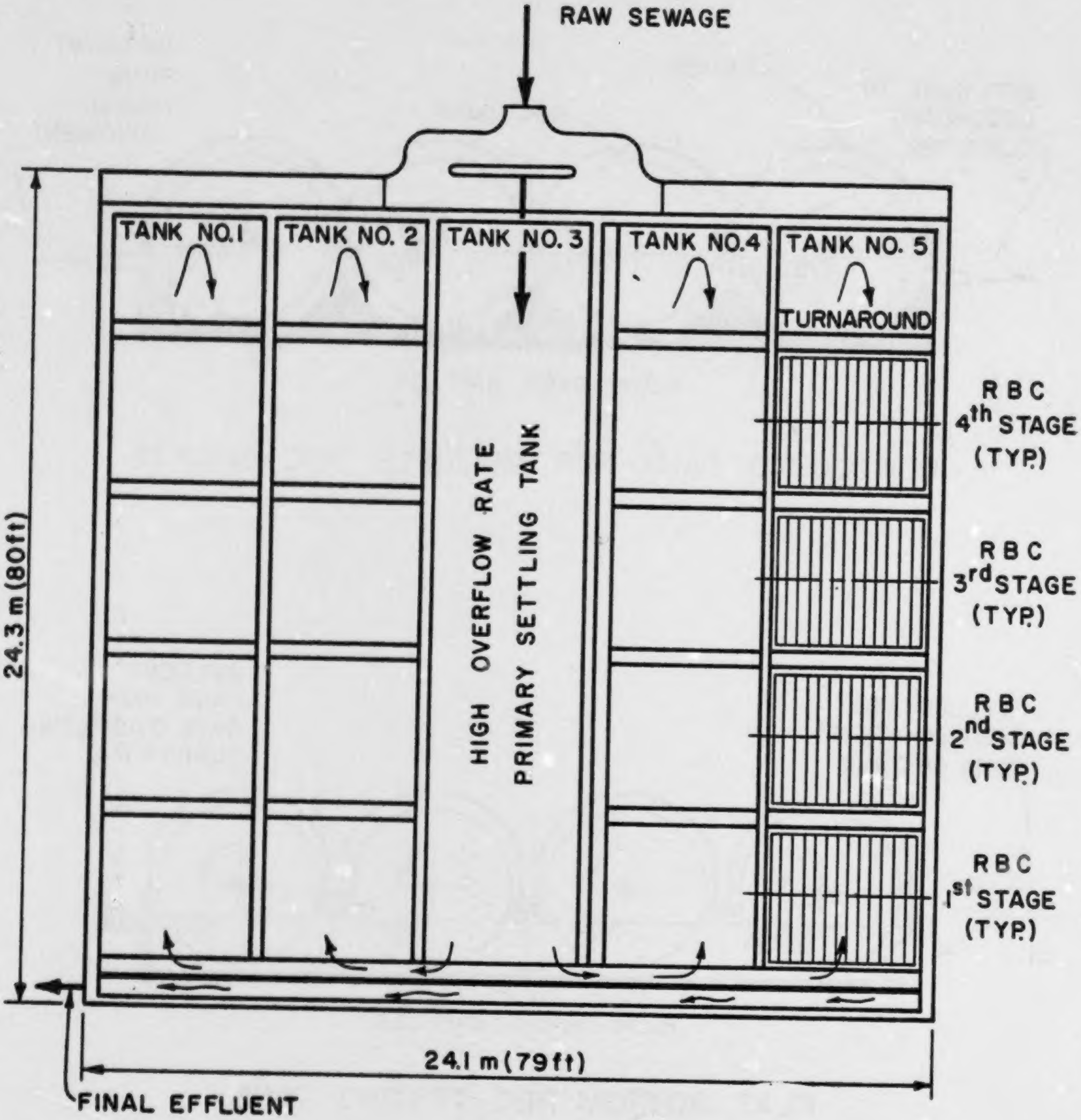

EFFLUENT TO SECONDARY CLARIFIER
COVER
RBC UNITS
INFLUENT FROM PRIMARY TREATMENT
FLOW OVER BAFFLES

CONTOURED TANK FOR MULTIPLE RBC SHAFTS


EFFLUENT TO SEDIMENTATION ZONE OF TANK
INFLUENT FROM HIGH RATE OVERFLOW CLARIFIER
FLOW UNDER BAFFLES

FLAT BOTTOM RBC TESTING TANK

Figure 42. RBC bottom configurations.


RAW SEWAGE
TANK NO.1
TANK NO. 2
TANK NO. 3
TANK NO.4
TANK NO. 5
TURNAROUND
HIGH OVERFLOW RATE
PRIMARY SETTLING TANK
RBC 4th STAGE (TYP.)
RBC 3rd STAGE (TYP.)
RBC 2nd STAGE (TYP.)
RBC 1st STAGE (TYP.)
24.3 m (80ft)
24.1 m (79ft)
FINAL EFFLUENT

PLAN

Figure 43. Layout example No. 1.

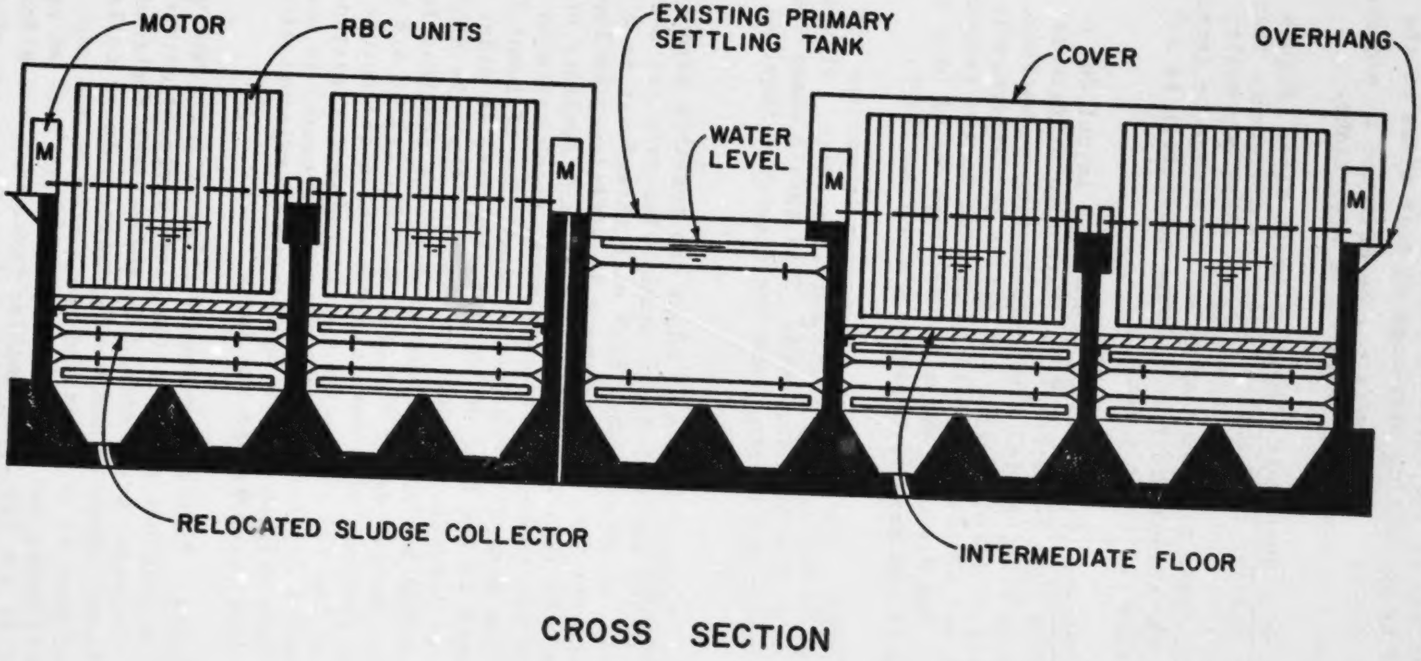

MOTOR
RBC UNITS
EXISTING PRIMARY SETTLING TANK
COVER
OVERHANG
WATER LEVEL
M
M
M
M
RELOCATED SLUDGE COLLECTOR
INTERMEDIATE FLOOR
CROSS SECTION

Figure 44. Layout example No. 1.

for a small plant consisting of two existing primary tanks. Minimal changes can be obtained by installing overhangs on both sides of the tank to accommodate the motors. The covers may be designed to enclose two shafts, which reduces the clearance required between tanks.

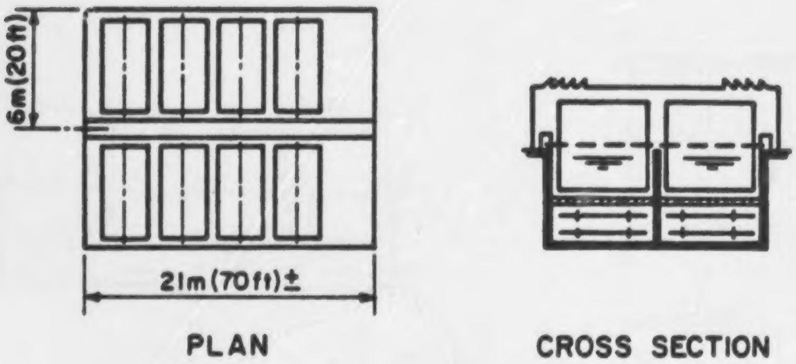
Example 3 - Small Plant with Two Tanks - Maximum Shaft Size. Figure 45(b) presents a layout similar to Example 2 with the difference that the width of the tank allows the use of the largest shaft now built, 7.6 m (25 ft) in length. In a case such as this, the sludge collectors must be in pairs since the normal width for sludge collectors is 6.1 m (20 ft) which is less than the shaft's length.

Example 4 - Extra-Wide Tanks. Figure 45(c) presents a layout for a tank with a width greater than 8.2 m (27 ft). This type of tank is usually divided into bays with several sludge-collecting mechanisms. A possible layout consists in accommodating the shafts perpendicularly to the sewage flow. Each set of shafts should be located in the respective bays of the tank. The dividing walls between bays would have to be extended to the top of the tank to separate the stream flows.

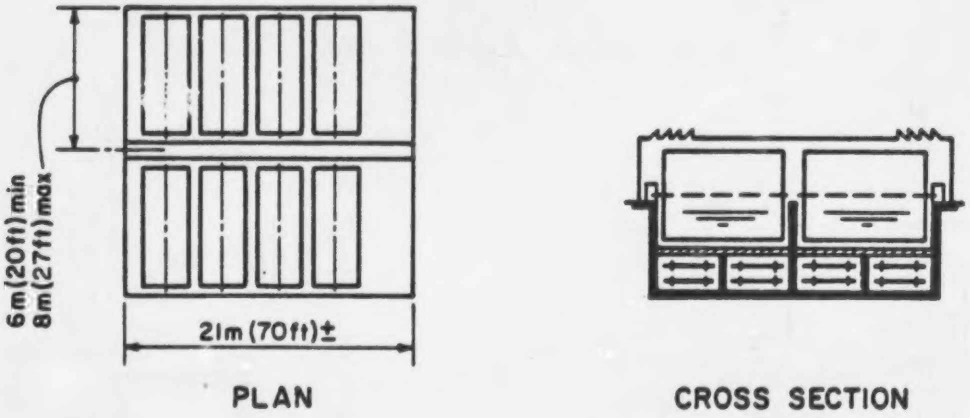
Example 5 - Multiple Tanks. Figure 46(a) presents a layout for the installation of RBC units in multiple adjacent settling tanks. Figure 46(b) presents a detail of the dividing wall. This detail shows the space required by the motor and bearings and the clearance required to service the motor.

Example 6 - Extra-Large Tanks. Figure 47 shows two possible layouts for the installation of RBC units in large tanks. The original settling facilities consist of three tanks, each with three bays 64 m (210 ft) long. Since it appears that the increment in efficiency is low for more than four stages, the layout for this type of tank consists of making subdivisions to the tanks to the upper zone, which contains the RBC units. The settling zone is a continuous zone. The effluent from the RBC units is brought to the head of the settling zone in order to provide adequate solids removal. It must be observed that the RBC/Underflow Clarifier method may present some maintenance problems for such large tanks. The shallow depth of the clarifier, 1.2 to 1.8 m (4 to 6 ft), may present problems with servicing the chain collectors in long tanks. If one of the RBC shafts located in the center portion should have to be removed for service, it would be necessary to use long-reach cranes. This problem may be aggravated by adjacent structures or lack of adequate free space around the tank.

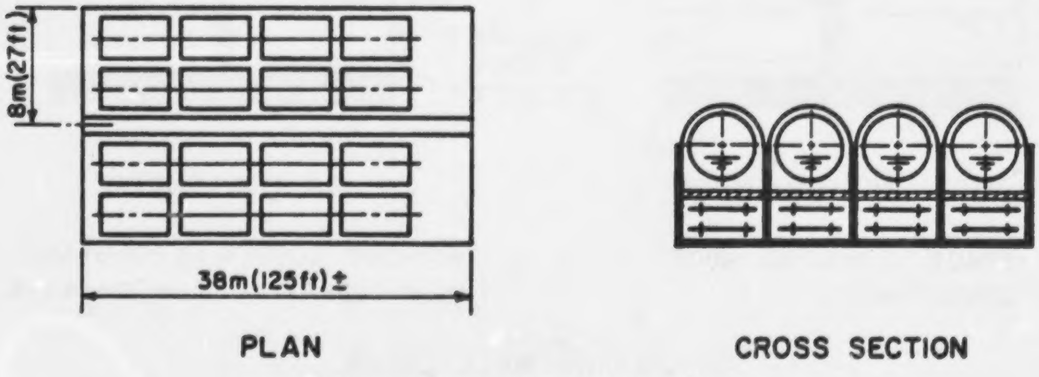
Example 7 - Square Tanks. Figure 48 presents a layout for a medium-size square tank. The original sludge collectors, influent entrance, peripheral effluent channels, etc., should be removed and replaced with new influent and effluent channels and a longitudinal sludge collector. An intermediate floor must be provided and the bottom of the tank has to be leveled. Square tanks can be converted when they have an approximate side length of 24.4 m (80 ft). Smaller tanks will not allow the installation of four stages unless the RBC units selected are of the small-diameter type. Very large tanks must be divided as in Example 6.


6m(20ft)
21m(70ft)±
PLAN
CROSS SECTION

(a) LAYOUT EXAMPLE NO. 2.

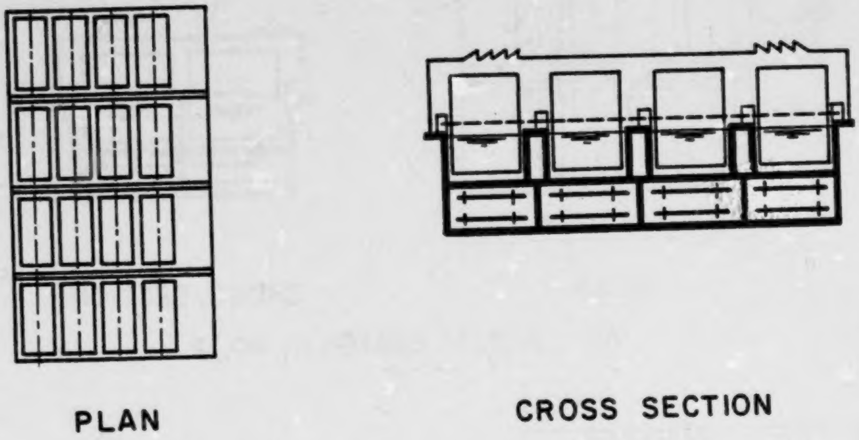

6m(20ft)min
8m(27ft)max
21m(70ft)±
PLAN
CROSS SECTION

(b) LAYOUT EXAMPLE NO. 3.

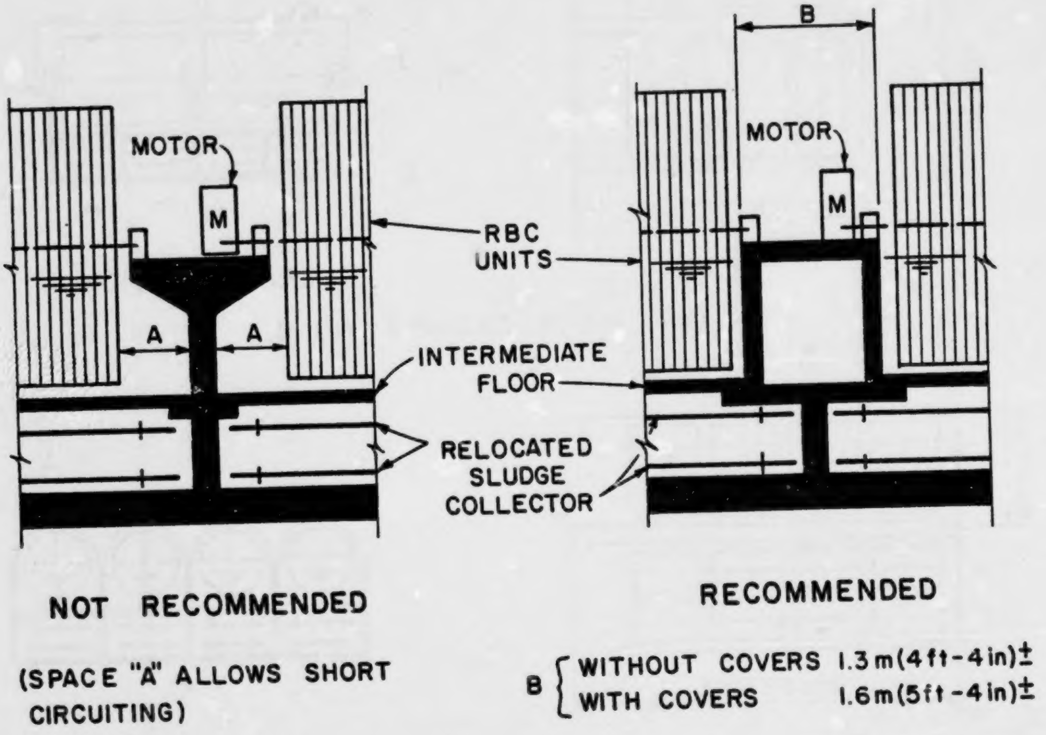

8m(27ft)
38m(125ft)±
PLAN
CROSS SECTION

(c) LAYOUT EXAMPLE NO. 4.

Figure 45. RBC layouts in small tanks.


PLAN
CROSS SECTION

(a) LAYOUT EXAMPLE NO. 5.


B
MOTOR
M
MOTOR
M
RBC UNITS
A
A
INTERMEDIATE FLOOR
RELOCATED SLUDGE COLLECTOR
NOT RECOMMENDED
RECOMMENDED
(SPACE "A" ALLOWS SHORT CIRCUITING)
B { WITHOUT COVERS 1.3 m(4 ft-4 in)±
WITH COVERS 1.6 m(5 ft-4 in)±

(b) DIVIDING WALL DETAIL

Figure 46. Layout and dividing wall detail for adjacent tanks.

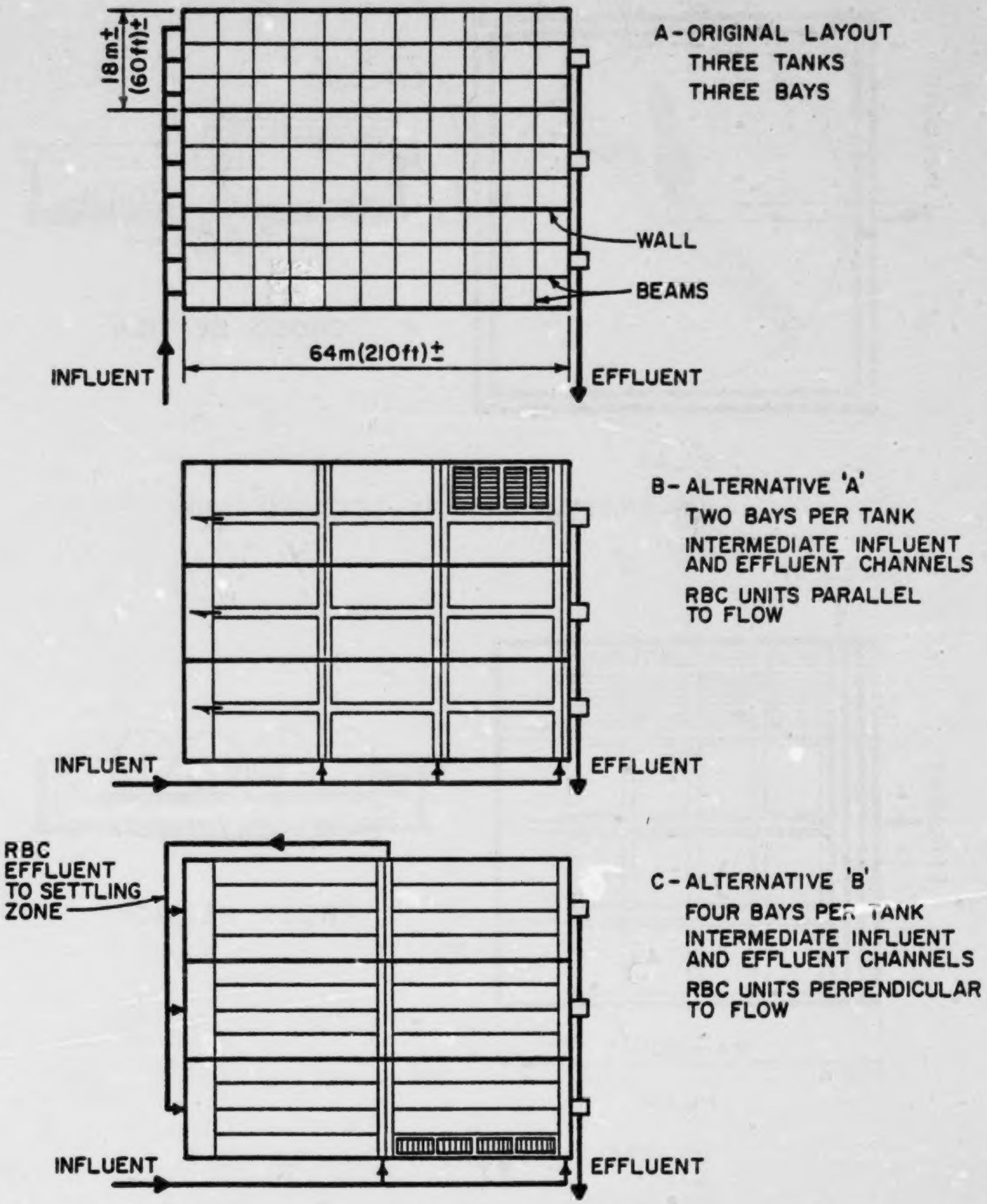
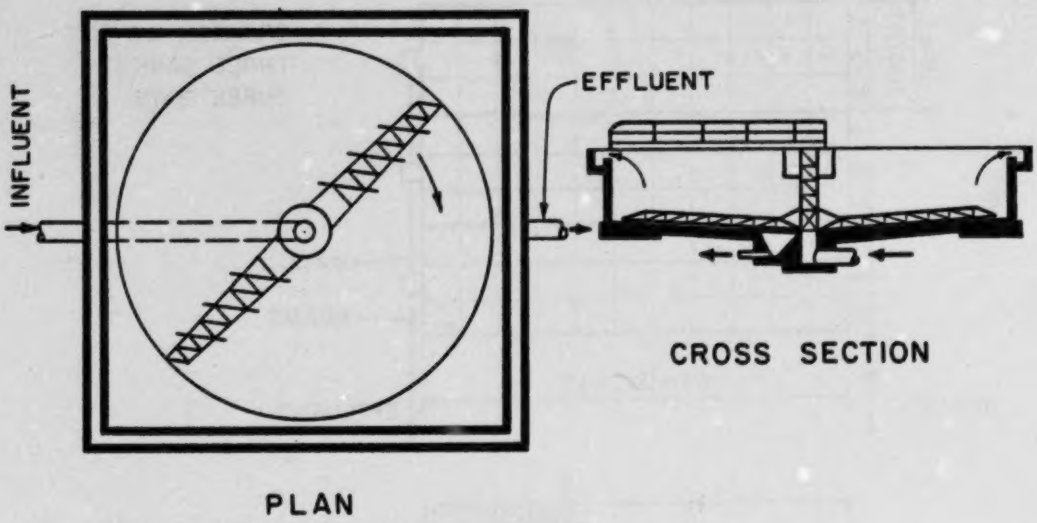
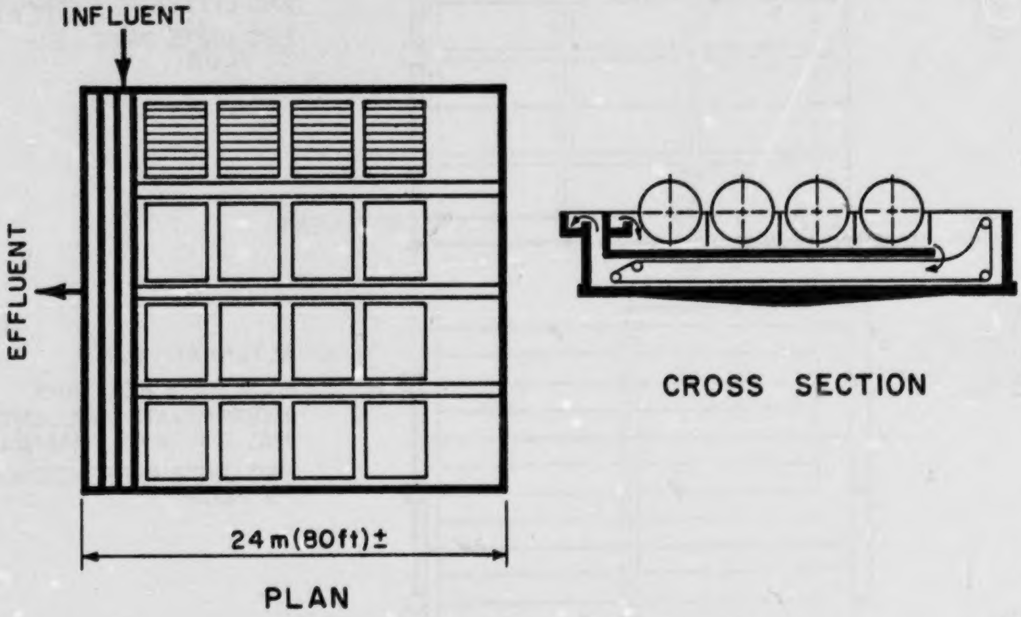

18m±
(60ft)±
A-ORIGINAL LAYOUT
THREE TANKS
THREE BAYS
WALL
BEAMS
64m(210ft)±
INFLUENT
EFFLUENT
B-ALTERNATIVE 'A'
TWO BAYS PER TANK
INTERMEDIATE INFLUENT AND EFFLUENT CHANNELS
RBC UNITS PARALLEL TO FLOW
INFLUENT
EFFLUENT
RBC EFFLUENT TO SETTLING ZONE
C-ALTERNATIVE 'B'
FOUR BAYS PER TANK
INTERMEDIATE INFLUENT AND EFFLUENT CHANNELS
RBC UNITS PERPENDICULAR TO FLOW
INFLUENT
EFFLUENT

Figure 47. RBC layouts in large tanks (Example No. 6).


INFLUENT
EFFLUENT
CROSS SECTION
PLAN

(a) ORIGINAL PRIMARY SETTLING TANK.


INFLUENT
EFFLUENT
CROSS SECTION
24 m(80ft)±
PLAN

(b) RBC INSTALLATION EXAMPLE NO. 7.

Figure 48. RBC layout in medium size square tank.

LIMITATIONS

There are several limitations on upgrading primary treatment plants using the RBC/Underflow Clarifier concept. It must again be noted that there are no typical solutions and that each plant presents particular limitations either in physical aspects or in design loadings. These limitations include:

(1) Depth. A depth of at least 3.05 m (10 ft) is required for this process in order to provide adequate space for the RBC units, the intermediate floor and the underflow clarifier.

(2) Width. The prior examples address, in part, the problem of width. Since the RBC units require clearances on both sides, the length of each shaft is substantially reduced in narrow tanks. Very wide tanks may have to be divided.

(3) Length. The length of the tank must be adequate to allow the installation of the number of stages required. In some cases it may be necessary to use two or three shafts per stage.

(4) Weight. Three loads should be considered in designing an RBC unit: the drive weight and the two bearing loads. The bearing load closer to the drive unit is larger because of the main drive sprocket and chain casing. Each manufacturer should specify these loads, which will change with the size of the drive unit and the shaft length. Typical weights may be of the order of 1,190 kg/m (800 lbs/ft) for new dry shaft and 2,830 kg/m (1,900 lbs/ft) for wet shaft with biomass.

OTHER CONSIDERATIONS

Maintenance --

The simplicity of the equipment makes maintenance a relatively easy task. A drive unit consists of an electric motor, belt drive, gear reducer and chain drive. A shaft is supported by two bearings. The following maintenance description and discussion of problems refer not only to the one-year testing period under this program but the five years' experience obtained at Edgewater since the installation of the RBC system.

Lubrication --

Shaft bearings have been checked on a weekly basis and lubricated as needed. This has averaged about once every two weeks. The external grease fittings made it possible to lubricate the bearings with the covers on at all times. However, during the winter, with the side covers on, it was not possible to check and lubricate the gear reducer (to date, this has not presented any problems). Since the Edgewater covers were not provided with entrance doors, the general practice has been to remove half of the side cover during the spring and replace it at the beginning of winter. The design of new covers provides entrance doors which facilitate maintenance and inspection of the drive units. The oil in the gear reducer has been changed once a year. In general, lubrication was performed following the manufacturer's recommendations. The average annual cost of oil and grease was $50 per drive unit.

Covers --

As mentioned before, the Edgewater covers were not provided with access doors. Removable windows allowed inspection of the media in several places. The panels overlapped each other and were attached to the floor with pin locks. Vibration and wind effects show this to be a poor anchoring system. At one point, with half of the side cover removed, a strong wind resulted in the cover's losing several pins. The treatment plant personnel secured the covers with ropes, thus protecting them from being destroyed by the wind. It has also been observed that the operation of side cover removal has deteriorated some of the side covers. Sometimes it is necessary to remove the end panels to service the drive units. It is, therefore, essential that the RBC covers be secured but also easy to take apart.

Drive Unit Service --

During the five-year period it was necessary to service one gear reducer and two bearings. This service required the use of a crane to remove and replace the gear reducer. For large plants with multiple shafts, side by side, sufficient space to operate a crane should be provided. Since it is not a good practice to keep a shaft out of service for a long time because of the unbalanced growth that will occur on the media, it is advisable to maintain sufficient spare parts for the RBC units.

Sludge Collecting Mechanism --

This equipment was inspected several times and repaired before the start of the program. The inspection and service required that the tank be completely drained. The chains and flights required a week to repair. The intermediate floor provides a clarifier depth of 1.42 m (4 ft 8 in) which made welding very difficult.

Sludge Accumulations --

During the course of the testing program, it was observed that some sludge accumulated under or near the baffles separating the stages. The original clearance of 0.15 m (6 in) was reduced to 0.05 m (2 in) increasing by three times the horizontal velocity at these points. Sludge accumulations on the intermediate floor can also be removed by dewatering the RBC unit to just below the intermediate floor.

Odors --

During the summer months, with the side covers off, a very unpleasant odor was detected at night during low loading to the RBC units. The odor problem may be associated with high temperatures, hydrogen sulfide production, beggiatoa growth, air stagnation, etc.

Insects --

The continuous rotation and wetting of the biomass prevents the attraction and breeding of insects, particularly flies, associated with some other secondary treatment processes.

Power Consumption

Power consumption measurements were made using a wattmeter on each drive motor. The electrical power consumption for Shaft No. 4 equipped with high-density media was five percent higher than that for Shafts 1, 2 and 3. There was no appreciable difference in power consumption between the first stage and subsequent stages. The shafts at Edgewater each contain 3.9 m (13 ft) of media. Scaling the power measurements to the standard maximum shaft length of 7.6 m (25 ft) results in an average power consumption of just over 3.73 kwhr/shaft (5 HP). Table 17 presents the power consumption.

TABLE 17. GENERALIZED POWER CONSUMPTION

Stage	kwhr.	(HP)	kwhr.	(HP equivalent)
	3.9 m	(13 ft) of media	7.6 m	(25 ft) of media
1,2,3	1.84	(2.5)	3.64	(4.8)
4	1.99	(2.6)	3.83	(5.1)
		Average	3.73	(5.0)

SECTION 10

COST ANALYSIS OF EDGEWATER MODIFICATIONS

As mentioned before, there is no "typical" existing primary treatment plant to illustrate the upgrading process since, in general, there is no "typical" plant nor sewage. In order to illustrate the costs associated with "upgrading primary treatment plants with the RBC/Underflow Clarifier system" a comparison of four estimates to upgrade the Edgewater Treatment Plant is presented. Two of these estimates consider the use of mechanical drives and the other two consider the use of air drives and chemicals to enhance solids removal.

CONSTRUCTION COSTS

The construction costs include those structural, mechanical, electrical and control features within the limits of the RBC process as well as the connecting piping and the land required to accommodate the new units required.

The cost estimates are based on costs incurred in 1972 to convert one tank for the test module, upgraded to 1978 costs using the ENR annual factors, the present costs of equipment, and current construction costs for the New York Metropolitan Area. To develop total construction costs, it is necessary to add appropriate amounts for engineering; legal, fiscal and administrative functions; interest during construction and contingencies to cover other costs of general work not directly associated with any item of the cost estimate.

To estimate the construction costs, the facilities were defined by dimension, construction material, equipment, piping and appurtenant requirements.

The construction cost estimates are presented in Tables 18 through 21. The main items include:

Sludge Collectors. Costs are presented for chain sludge collection equipment in rectangular basins. To modify existing tanks to the RBC/Underflow Clarifier process it will be necessary to relocate the sludge collectors.

Concrete Removal. Costs are presented for removal of cross-beams to allow the installation of the 3.61 m (12 ft) (diameter) shafts.

New Concrete. Cost estimates include concrete, reinforcing steel, labor, etc., for the new concrete required for influent and effluent channels, motor supports, new cross-beams, intermediate floor supports and for the new additional concrete tanks.

Intermediate Floor. The intermediate floor required by the RBC/ Underflow Clarifier process was considered a separate item in cost estimating. The intermediate floor was considered to be constructed of precast slabs 0.15 m (6 in) thick.

RBC Media and Covers. This item includes estimated purchase costs of process equipment and other items which are factory-made.

RBC Installation. An amount equal to 10 percent of the RBC media was taken for this item.

Electrical Work. A unit cost per shaft was considered for the RBC equipment. In addition, 10 percent of the cost of other equipment was considered for this item.

Piping. This item includes the purchase and installation price of all types of pipes, valves, fittings and support devices grouped as a single component.

Baffles. These were considered to be made from 0.05 m by 0.15 m (2 in by 6 in) redwood planks.

Blowers and Mixers. These two items include the estimated purchase cost of the equipment including the installation costs.

Engineering, Contingencies, etc. Under this item, we have grouped the costs associated with all the basic and special engineering services, the cost of legal and fiscal services, the administrative services, the interest during construction and the cost of contingencies. All these costs may be substantial and will vary with the size complexity of the project. A value equal to 50 percent of the total construction cost was used for this item.

OPERATION AND MAINTENANCE

Operation and maintenance requirements had been established during the operation of the pilot plant in Edgewater.

Labor. The manpower requirements refer to the RBC/Underflow Clarifier. They do not include any allowance for general plant administration, laboratory work or other plant manpower requirements.

Power. Cost estimates are based on power requirements for the RBC units and other equipment related to this process.

Supplies. This item includes the oil, grease and other supplies required for the RBC equipment.

Aeration Equipment. Operation and maintenance manpower for the aeration equipment was obtained from charts given in the EPA publication "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities," published in 1971. The estimated operation and maintenance labor requirements are for diffused air systems according to the blower capacity.

Material and supply cost estimates were derived from the same source.

MECHANICAL DRIVES

Case 1

As described in Section 8 and presented in Table 16, a total of nine tanks with four 4.1 m (13.5 ft) shafts would be required to provide the total surface area to meet the effluent BOD_5 criteria under peak monthly conditions. For the first cost estimate, we have considered that one of the five existing settling tanks would be used to provide the necessary high-rate primary treatment for the entire plant flow. The remaining four tanks would be converted to the RBC/Underflow Clarifier process and three new tanks, two of them accommodating 7.62 m (25 ft) shafts and one accommodating a 5.50 m (18 ft) shaft would be constructed. This arrangement provides as equal amount of surface area as the five 4.1 m (13.5 ft) shafts, but is more economical in the new concrete required. All the RBC/Underflow Clarifier tanks would be divided with a six-inch thick intermediate floor. Table 18 presents the summary of costs, and Figure 49 shows the schematic layout for this alternative.

Case 2

The second cost estimate considers the construction of one high-rate primary settling tank to provide an overflow rate of 2,500 gpd/ft^2 and five tanks with four 7.62 m (25 ft) shafts each, which would be equivalent to the nine tanks required with 4.1 m (13.5 ft) shafts. The tanks would be only 1.80 m (6 ft) deep since they will not provide the underflow clarifier. The existing settling tanks would be used as secondary clarifiers. Table 19 presents the summary of cost estimates for this case, and Figure 49 shows the schematic layout of this alternative.

AIR DRIVES AND CHEMICAL ADDITION

Case 3

As described in Section 8, interstage aeration and chemical addition to the fourth stage mixed liquor effluent would require seven tanks with four 4.1 m (13.5 ft) tanks instead of nine tanks as described for the mechanical drives. The design modifications are an hypothetical case since this alternative was not evaluated on a full-scale basis. It is presented here in order to present a cost comparison with the mechanical drives. It is claimed that the air-drive RBC systems provide the aeration required to keep the DO levels at 5.0 mg/l

TABLE 18. COST ESTIMATES: MECHANICAL DRIVES - CASE 1

Construction cost estimate:

	Costs to modify existing tanks	Costs of additional tanks
Sludge collectors	$ 30,800	$ 73,500
Concrete removal	22,800	-
New concrete	38,200	144,100
Intermediate floor	46,200	60,500
RBC media and covers	549,600	502,400
RBC installation	55,000	50,300
Electrical work	67,100	55,300
Piping	-	10,000
Baffles	5,500	7,200
Land	-	25,000
	$ 815,200	$ 928,300

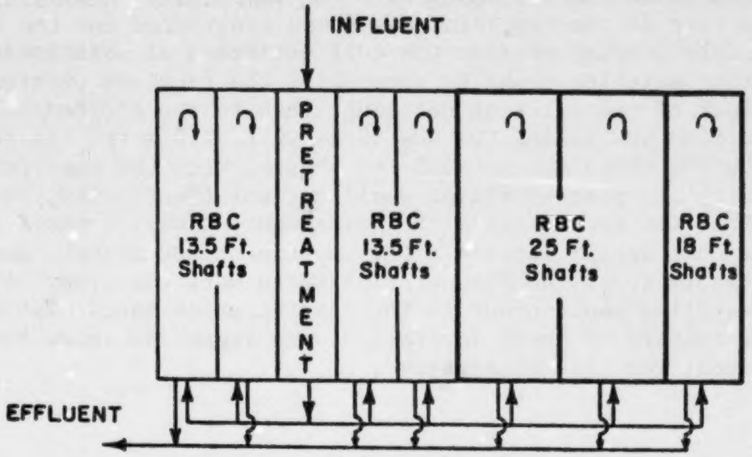
Sub-total	$ 1,743,500
Engineering, contingencies, etc. @ 50%	$ 817,750
Total construction cost	$ 2,615,250

O & M cost estimate:

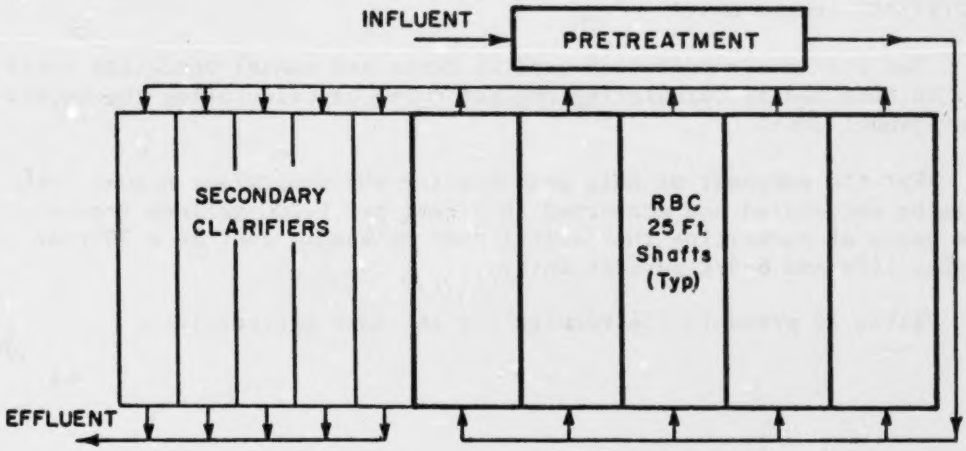
Labor	$ 7,300
Power	26,000
Supplies	1,400
Total Annual O&M Cost	$ 34,700

TABLE 19. COST ESTIMATES: MECHANICAL DRIVES - CASE 2

Construction cost estimate:	
Sludge collectors	$ 24,500
New concrete	205,700
RBC media and covers	858,500
RBC installation	85,800
Electrical work	82,500
Piping	40,500
Baffles	4,200
Land	50,000
Settling Tank Restoration	20,000
Sub-total	$1,371,700
Engineering, contingencies, etc. @ 50%	$ 685,850
Total construction cost	$2,057,550
O & M cost estimate:	
Labor	$ 5,200
Power	27,100
Supplies	1,000
Total Annual O&M Cost	$ 33,300


INFLUENT
PRETREATMENT
RBC 13.5 Ft. Shafts
RBC 13.5 Ft. Shafts
RBC 25 Ft. Shafts
RBC 18 Ft Shafts
EFFLUENT

CASE I - RBC / UNDERFLOW CLARIFIERS
ESTIMATED ANNUAL COST $ 0.29 PER 1,000 GALLONS


INFLUENT
PRETREATMENT
SECONDARY CLARIFIERS
RBC 25 Ft. Shafts (Typ)
EFFLUENT

CASE 2 - SEPARATED RBC UNITS
ESTIMATED ANNUAL COST $ 0.23 PER 1,000 GALLONS

Figure 49. Mechanical drives schematic layout.

throughout the system and at the same time provide the rotation required to accomplish the treatment with the RBC units. A similar arrangement to that of the preceding cases was considered for the cost estimates. Case 3 would present the cost estimates of maintaining one of the existing settling tanks to accomplish the required pretreatment, converting four of the existing settling tanks to the RBC/Underflow Clarifier process and adding two new tanks with 6.10 m (20 ft) shafts equivalent to the three 4.1 m (13.5 ft) shafts, with the same process. As described in the process design modifications (Section 8), it was considered that the mechanical mixing zone could occupy a small portion of the turnaround sector located after the fourth RBC stage. According to the laboratory tests, no flocculation tanks were required. Flocculation and settling would occur in the clarification zone. Table 20 presents the summary of costs for Case 3, and Figure 50 shows the schematic layout for this alternative.

Case 4

The fourth case considers an arrangement similar to that of Case 2, but including the air drive and the rapid mixers for the chemical addition. Four tanks with four 7.62 m (25 ft) shafts each would be equivalent to the seven tanks required with the 4.1 m (13.5 ft) shafts. Table 21 presents the cost estimates for Case 4, and Figure 50 shows the schematic layout for this alternative.

EQUIVALENT ANNUAL COSTS

The previously presented capital costs and annual operating costs may be combined by calculating present worth or calculating the equivalent annual cost.

For the purposes of this presentation the equivalent annual cost will be calculated and converted to a cost per 1,000 gallons treated. The basis of converting the capital cost to annual cost is a 20-year useful life and 6-5/8 percent interest.

Table 22 presents the results for the four alternatives.

TABLE 20. COST ESTIMATES: AIR DRIVES - CASE 3

Construction Cost Estimate:

	Costs to modify existing tanks	Costs of additional tanks
Sludge collectors	$ 30,800	$ 49,000
Concrete removal	22,800	-
New concrete	38,200	94,500
Intermediate floor	46,200	36,300
RBC media and covers	549,600	302,000
RBC installation	55,000	30,200
Blowers	15,900	15,900
Rapid mixers	40,000	40,000
Electrical work	72,700	40,500
Baffles	7,200	5,400
Land	-	16,000
Piping	3,000	9,700
Chemical storage tanks & dosing pumps		30,000
	$ 881,140	$ 649,500

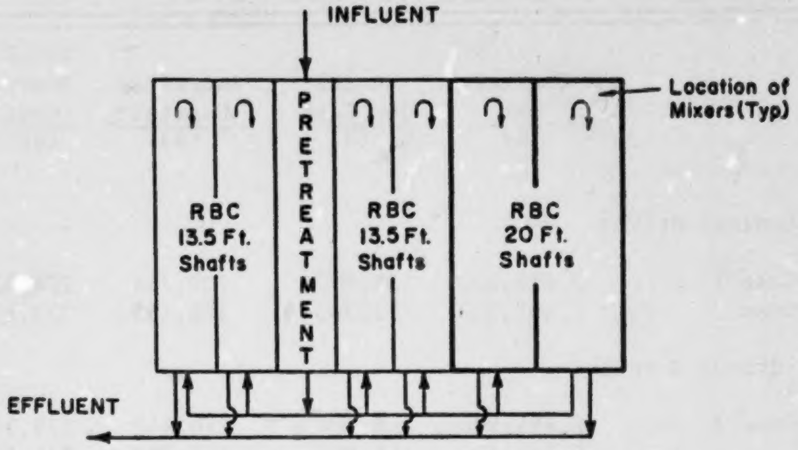
Sub-total	$1,530,600
Engineering, contingencies, etc. @ 50%	$ 765,300
Total construction cost	$2,295,900

O & M estimate:

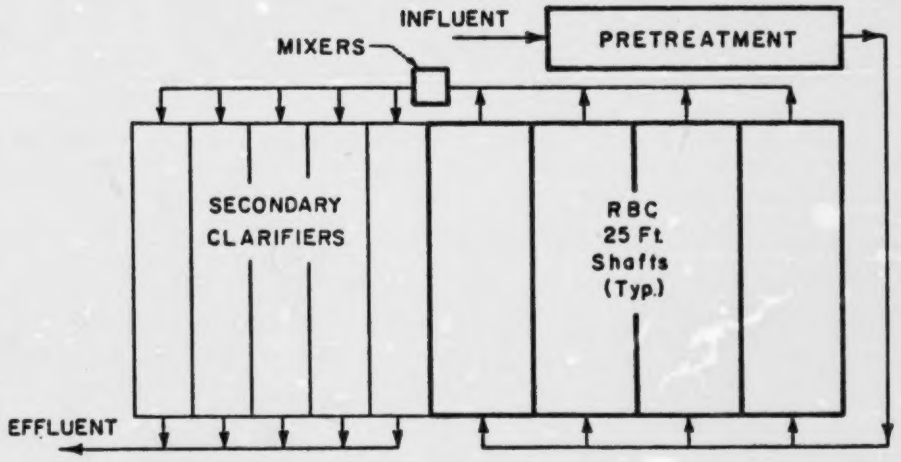
Labor	$ 21,100
Power	37,800
Supplies	3,200
Ferric chloride	6,800
Total Annual O&M Cost	$ 68,900

TABLE 21. COST ESTIMATES: AIR DRIVES - CASE 4

Construction cost estimate:	
Sludge collectors	$ 24,500
New concrete	172,400
RBC media and covers	686,800
RBC installation	68,700
Blowers	21,300
Rapid mixers	40,000
Electrical work	72,600
Piping	43,500
Baffles	4,200
Land	43,000
Settling tank restoration	20,000
Chemical storage & dosing pumps	30,000
	$1,227,000
Engineering, contingencies, etc. @ 50%	$ 613,500
Total Construction Cost	$1,840,000
O & M cost estimate:	
Labor	$ 23,200
Power	29,700
Supplies	3,200
Ferric chloride	6,700
Total Annual O&M Cost	$ 62,800


INFLUENT
Location of Mixers (Typ)
RBC 13.5 Ft. Shafts
PRETREATMENT
RBC 13.5 Ft. Shafts
RBC 20 Ft. Shafts
EFFLUENT

CASE 3 - RBC / UNDERFLOW CLARIFIERS
ESTIMATED ANNUAL COST $ 0.29 PER 1,000 GALLONS


INFLUENT
PRETREATMENT
MIXERS
SECONDARY CLARIFIERS
RBC 25 Ft. Shafts (Typ.)
EFFLUENT

CASE 4 - SEPARATED RBC UNITS
ESTIMATED ANNUAL COST $ 0.24 PER 1,000 GALLONS

Figure 50. Air drives and chemical treatment schematic layout.

TABLE 22. COMPARISON OF ALTERNATIVES

	Capital Cost ($)	Annual O&M Cost ($)	Amortized Capital* ($)	Total Annual Cost ($)	Unit Cost ($/1000 gal.)
Mechanical drives					
Case 1	2,615,250	34,700	239,714	274,414	0.29
Case 2	2,057,550	33,300	188,595	221,895	0.23
Air drives & $FeCl_3$					
Case 3	2,295,900	68,900	210,442	279,342	0.29
Case 4	1,840,500	62,800	168,700	231,500	0.24

*CRF = 0.09166, 20 years and 6-5/8% interest.

REFERENCES

1. Standard Methods for the Examination of Water and Wastewaters, APHA, WPCF, AWWA, 14th Edition, 1975.

2. Manual of Methods for Chemical Analysis of Water and Wastes, EPA-625/6-74-003, U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

3. Jeris, John S., "A Rapid COD Test," Water and Wastes Engineering, May 1967.

4. Antoine, Ronald L., Fixed Biological Surfaces-Wastewater Treatment, CRC Press, Inc., Cleveland, 1976.

APPENDIX A

TABULATION OF RAW DATA

TABLE A-1. EDGEWATER RAW DATA SUMMARY

Day	Date	Flow Plant	RBC (mgd)	RBC Sludge (gpd)	Temp. °C RBC		pH RBC	
					In	Out	In	Out
1	3/9/77	2.90	0.400	-	13.0	12.0	6.8	7.0
2	3/10/77	2.40	0.400	-	13.5	12.5	7.5	7.0
3	3/11/77	2.50	0.285	-	15.5	14.5	7.1	6.9
4	3/12/77	2.40	0.390	-	13.0	12.0	7.4	7.2
5	3/13/77	2.50	0.380	-	13.0	12.0	7.2	7.2
6	3/14/77	4.00	0.355	-	13.5	12.4	7.2	7.1
7	3/15/77	2.60	0.411	-	13.0	13.0	7.2	7.1
8	3/16/77	2.90	0.428	2,340	14.5	13.0	7.2	7.3
9	3/17/77	2.80	0.485	2,180	13.5	13.0	7.3	7.4
10	3/18/77	2.80	0.430	2,940	-	-	7.4	7.4
11	3/19/77	3.90	0.425	2,390	13.5	13.0	7.5	7.3
12	3/20/77	3.30	0.423	2,390	12.5	12.0	6.9	7.0
13	3/21/77	3.00	0.423	1,795	14.0	13.0	7.3	7.3
14	3/22/77	2.90	0.297	1,990	11.5	-	7.2	7.3
15	3/23/77	6.30	0.228	2.420	11.0	10.0	7.1	7.2
16	3/24/77	4.40	0.212	1,740	13.0	11.0	7.0	7.1
17	3/25/77	3.30	0.220	1,539	13.0	11.0	-	7.3
18	3/26/77	2.80	0.242	2,023	13.0	12.0	-	7.1
19	3/27/77	2.70	0.240	2,137	12.5	12.0	7.1	6.9
20	3/28/77	2.50	0.225	1,082	13.0	15.0	7.2	7.2
21	3/29/77	2.80	0.305	1,169	15.0	13.5	7.2	7.3
22	3/30/77	2.50	0.305	968	16.0	15.0	7.2	7.3
23	3/31/77	2.80	0.320	2,763	16.5	15.0	7.3	7.2
24	4/1/77	2.40	0.320	1,538	15.5	14.0	6.9	7.0
25	4/2/77	3.70	0.324	2,308	14.0	14.0	7.8	7.6
26	4/3/77	2.90	0.305	1,424	13.0	13.0	7.3	7.2
27	4/4/77	3.60	0.311	883	15.0	14.0	7.5	7.4
28	4/5/77	4.70	0.315	968	-	-	7.2	7.2
29	4/6/77	3.70	0.275	1,082	14.0	12.0	6.7	7.0
30	4/7/77	3.50	0.409	1,066	14.0	12.0	7.2	7.0
31	4/8/77	-	-	-	-	-	-	-
32	4/9/77	-	-	-	-	-	-	-
33	4/10/77	-	-	-	-	-	-	-
34	4/11/77	2.60	0.403	911	15.0	14.0	7.2	7.2
35	4/12/77	2.50	0.400	968	-	15.0	7.4	7.4

continued.

TABLE A-1. (continued)

Day	Date	Flow Plant	RBC (mgd)	RBC Sludge (gpd)	Temp. °C RBC In	Temp. °C RBC Out	pH RBC In	pH RBC Out
36	4/13/77	2.50	0.418	1,198	17.0	16.0	7.4	7.5
37	4/14/77	2.50	0.407	1,396	17.0	16.0	7.3	7.4
38	4/15/77	2.50	0.392	2,023	17.0	15.0	7.4	7.4
39	4/16/77	2.60	0.400	2,790	17.0	16.0	7.8	7.6
40	4/17/77	2.50	0.370	1,139	16.7	16.0	7.4	7.4
41	4/18/77	2.50	0.405	2,051	18.0	17.0	7.3	7.4
42	4/19/77	2.20	0.385	2,222	18.0	17.0	7.3	7.4
43	4/20/77	2.20	0.395	2,194	-	18.0	7.2	7.3
44	4/21/77	2.30	0.405	2,648	-	18.0	7.1	7.2
45	4/22/77	2.30	0.415	3,135	19.0	18.0	7.2	7.2
46	4/23/77	2.20	0.365	2,079	17.0	19.0	7.3	7.3
47	4/24/77	2.60	0.365	2,279	17.0	17.0	7.5	7.2
48	4/25/77	2.20	0.395	1,139	-	17.0	7.3	7.4
49	4/26/77	2.30	0.380	1,797	-	-	7.3	7.4
50	4/27/77	2.20	0.375	968	18.0	18.0	7.3	7.4
51	4/28/77	2.20	0.375	-	19.0	18.0	7.6	7.5
52	4/29/77	2.40	0.450	-	17.0	17.0	7.5	7.5
53	4/30/77	2.20	0.380	-	18.0	17.0	7.3	7.4
54	5/1/77	2.20	0.370	-	18.0	17.0	7.2	7.1
55	5/2/77	2.00	0.390	-	17.0	18.0	7.1	7.1
56	5/3/77	2.10	0.390	-	17.0	18.0	7.1	7.1
57	5/4/77	1.80	0.407	1,852	19.0	18.0	6.6	6.8
58	5/5/77	2.60	0.388	1,567	18.0	17.0	7.0	7.2
59	5/6/77	2.30	0.230	712	19.0	19.0	6.9	6.8
60	5/7/77	3.10	0.360	2,849	-	-	-	-
61	5/8/77	2.70	0.345	2,336	18.0	17.0	7.2	7.0
62	5/9/77	2.60	0.365	1,909	18.0	16.5	6.9	6.9
63	5/10/77	2.60	0.370	2,335	18.0	17.0	6.9	7.0
64	5/11/77	2.20	0.369	1,851	19.0	18.0	7.0	7.0
65	5/12/77	2.40	0.368	1,079	19.0	19.0	7.0	7.0
66	5/13/77	2.40	0.370	3,162	20.0	19.0	6.8	7.6
67	5/14/77	2.30	0.380	3,247	19.0	19.0	7.1	7.2
68	5/15/77	2.30	0.350	1,824	18.0	19.0	7.1	7.1
69	5/16/77	2.10	0.365	1,882	20.0	20.0	7.2	7.2
70	5/17/77	2.30	0.680	2,109	21.0	20.0	7.1	7.2
71	5/18/77	2.10	0.775	2,907	21.5	20.0	7.2	7.3
72	5/19/77	2.30	0.840	2,906	21.0	21.0	7.2	7.2
73	5/20/77	2.10	0.660	3,390	21.5	21.0	7.2	7.2
74	5/21/77	2.20	0.618	3,595	21.0	21.0	7.6	7.2
75	5/22/77	2.20	0.632	1,994	21.0	21.0	7.1	7.2

continued.

TABLE A-1. (continued)

Day	Date	Flow Plant	RBC (mgd)	RBC Sludge (gpd)	Temp. °C RBC		pH RBC	
					In	Out	In	Out
76	5/23/77	2.00	0.618	2,251	23.0	22.0	6.8	7.2
77	5/24/77	2.20	0.717	2,450	23.0	23.0	6.9	7.0
78	5/25/77	2.10	0.678	2,548	23.0	23.0	6.8	6.9
79	5/26/77	2.10	0.558	2,133	23.0	22.0	7.2	7.3
80	5/27/77	2.10	0.625	2,251	23.0	23.0	7.3	7.2
81	5/28/77	2.20	0.585	2,250	23.0	23.0	7.5	7.4
82	5/29/77	2.00	0.260	3,076	19.0	22.0	6.8	7.0
83	5/30/77	1.90	0.480	1,453	21.0	21.0	7.1	7.2
84	5/31/77	1.80	0.685	2,763	23.0	23.0	7.0	7.1
85	6/1/77	2.00	0.685	3,988	23.0	23.0	7.1	7.2
86	6/2/77	2.10	0.670	5,357	23.5	23.5	7.2	7.3
87	6/3/77	2.10	0.685	4,445	24.0	23.0	7.0	7.0
88	6/4/77	2.00	0.685	4,231	22.0	22.0	6.9	7.0
89	6/5/77	2.10	0.685	2,393	22.0	22.0	6.7	6.8
90	6/6/77	2.00	0.640	3,875	24.0	23.0	7.2	7.3
91	6/7/77	2.60	0.655	7,921	23.0	22.0	7.3	7.3
92	6/8/77	1.90	0.570	2,252	23.0	22.0	6.7	6.9
93	6/9/77	2.20	0.710	3,901	-	-	-	-
94	6/10/77	4.30	0.670	1,453	-	-	-	-
95	6/11/77	3.10	0.305	3,249	22.0	21.0	7.9	7.9
96	6/12/77	2.30	0.695	2,136	22.0	21.0	7.3	7.5
97	6/13/77	1.90	0.935	2,194	23.0	22.5	7.5	7.5
98	6/14/77	2.10	0.698	2,991	23.5	23.0	8.8	8.5
99	6/15/77	1.90	0.696	1,595	23.5	23.5	7.9	7.8
100	6/16/77	2.20	0.710	2,421	24.0	23.5	7.5	7.5
101	6/17/77	2.10	0.705	3,019	24.0	24.0	7.5	7.5
102	6/18/77	2.30	0.705	3,943	24.0	24.0	7.8	7.6
103	6/19/77	2.30	0.711	3,162	-	-	-	-
104	6/20/77	2.10	0.711	3,969	25.0	24.5	7.3	7.4
105	6/21/77	2.40	0.635	2,821	25.0	24.0	7.3	7.4
106	6/22/77	2.00	0.725	1,396	24.0	24.0	7.7	7.4
107	6/23/77	2.20	0.695	3,078	24.5	24.0	7.3	7.4
108	6/24/77	2.30	0.720	2,310	25.0	25.0	7.5	7.5
109	6/25/77	2.30	0.700	3,696	24.0	24.0	8.4	8.0
110	6/26/77	2.40	0.685	3,619	24.0	24.0	7.1	7.5
111	6/27/77	2.10	0.685	3,962	25.0	24.5	7.2	7.3
112	6/28/77	2.10	0.685	2,298	24.0	24.0	7.3	7.4
113	6/29/77	2.30	0.720	2,566	25.5	25.0	7.2	7.4
114	6/30/77	2.20	0.945	2,764	25.5	25.5	7.3	7.6
115	7/1/77	1.80	0.770	2,165	25.5	25.5	7.6	7.6

continued.

TABLE A-1. (continued)

Day	Date	Flow Plant	RBC (mgd)	RBC Sludge (gpd)	Temp. °C RBC		pH RBC	
					In	Out	In	Out
116	7/2/77	2.20	0.555	-	-	-	-	-
117	7/3/77	2.10	0.500	-	-	-	-	-
118	7/4/77	1.90	0.495	-	-	-	-	-
119	7/5/77	2.00	0.490	-	-	-	-	-
120	7/6/77	2.30	0.550	2,736	27.0	26.0	7.3	7.5
121	7/7/77	2.10	0.530	2,365	26.0	26.0	7.3	7.4
122	7/8/77	2.10	0.507	2,336	26.0	26.0	7.5	7.6
123	7/9/77	2.30	0.527	3,733	30.0	29.0	7.2	6.8
124	7/10/77	2.00	0.465	3,760	29.0	30.0	7.4	7.2
125	7/11/77	1.90	0.460	3,106	26.5	26.0	7.3	7.5
126	7/12/77	2.10	0.495	3,933	26.0	25.0	7.3	7.4
127	7/13/77	2.30	0.475	3,306	27.0	26.5	7.1	7.1
128	7/14/77	1.90	0.495	4,416	27.0	27.0	7.1	7.1
129	7/15/77	2.10	0.475	3,078	27.0	27.0	7.1	7.1
130	7/16/77	2.30	0.400	3,675	27.0	27.0	7.2	7.3
131	7/17/77	2.00	0.492	2,222	27.0	27.0	7.1	7.2
132	7/18/77	1.90	0.470	1,880	28.0	27.5	7.3	7.5
133	7/19/77	2.30	0.482	2,650	28.0	28.0	7.1	7.0
134	7/20/77	2.00	0.492	2,079	28.5	28.0	7.3	7.3
135	7/21/77	2.20	0.485	2,421	28.0	28.0	7.0	7.1
136	7/22/77	2.20	0.502	2,421	28.0	28.0	7.4	7.4
137	7/23/77	2.20	0.515	3,020	27.0	27.0	7.4	7.4
138	7/24/77	2.00	0.480	4,104	27.0	27.0	7.2	7.4
139	7/25/77	1.90	0.490	2,790	28.0	27.0	7.2	7.3
140	7/26/77	2.30	0.490	4,445	27.0	26.5	7.2	7.3
141	7/27/77	1.90	0.495	2,192	27.0	27.0	7.3	7.3
142	7/28/77	2.10	0.485	2,023	-	-	-	-
143	7/29/77	2.10	0.210	-	27.5	27.5	7.6	7.6
144	7/30/77	2.30	0.430	3,049	26.0	26.5	7.4	7.4
145	7/31/77	2.10	0.395	3,020	27.0	26.0	7.3	7.3
146	8/1/77	1.90	0.390	3,305	27.5	27.0	7.2	7.3
147	8/2/77	2.50	0.410	2,849	27.0	26.0	7.4	7.4
148	8/3/77	2.00	0.435	2,763	27.0	27.0	7.4	7.4
149	8/4/77	2.30	0.405	2,393	27.0	26.0	7.2	7.3
150	8/5/77	2.20	0.420	3,106	27.0	27.0	7.2	7.3
151	8/6/77	2.20	0.440	2,307	27.0	27.5	7.5	7.4
152	8/7/77	2.10	0.405	2,536	27.0	27.0	7.4	7.4
153	8/8/77	2.20	0.390	2,449	27.0	27.0	7.1	7.4
154	8/9/77	2.10	0.415	1,879	27.0	27.0	7.5	7.1
155	8/10/77	2.20	0.385	1,595	27.0	27.0	7.4	7.4

continued.

TABLE A-1. (continued)

Day	Date	Flow Plant	RBC (mgd)	RBC Sludge (gpd)	Temp. °C RBC In	Temp. °C RBC Out	pH RBC In	pH RBC Out
156	8/11/77	1.90	0.395	2,619	27.0	27.0	7.2	7.3
157	8/12/77	2.30	0.385	2,478	-	-	-	-
158	8/13/77	2.30	0.400	2,535	27.0	27.0	7.3	7.2
159	8/14/77	1.90	0.328	1,794	27.0	26.5	7.2	7.2
160	8/15/77	2.00	0.385	2,735	27.5	27.0	-	6.0
161	8/16/77	2.00	0.393	2,707	27.0	26.5	6.9	6.8
162	8/17/77	2.40	0.408	1,938	27.0	27.0	7.2	7.3
163	8/18/77	2.30	0.395	2,108	27.0	26.0	7.2	7.3
164	8/19/77	2.30	0.388	2,221	27.0	26.0	7.0	7.0
165	8/20/77	2.30	0.390	2,079	26.0	26.0	[illegible].4	7.4
166	8/21/77	2.40	0.410	1,851	25.0	25.0	6.8	7.0
167	8/22/77	3.60	0.365	1,823	23.0	24.0	6.9	7.1
168	8/23/77	2.50	0.385	1,481	26.0	26.0	7.1	6.5
169	8/24/77	2.30	0.380	2,307	26.5	26.0	6.3	6.5
170	8/25/77	2.30	0.375	1,908	25.0	24.0	6.0	7.0
171	8/26/77	2.40	0.395	2,081	25.0	25.0	7.0	7.0
172	8/27/77	2.10	0.373	1,595	26.0	25.0	7.6	7.5
173	8/28/77	2.00	0.370	1,710	26.0	26.0	7.2	7.3
174	8/29/77	2.30	0.330	1,681	27.0	27.0	7.4	7.5
175	8/30/77	2.00	0.380	2,450	27.0	27.0	7.3	7.4
176	8/31/77	2.30	0.383	2,736	27.0	26.0	6.5	6.9
177	9/1/77	2.30	0.375	1,823	27.0	27.0	6.4	6.3
178	9/2/77	2.40	0.375	1,171	28.0	27.0	7.0	7.0
179	9/3/77	2.30	0.373	1,680	27.0	27.0	6.9	7.0
180	9/4/77	2.20	0.380	1,823	26.0	26.0	7.3	7.2
181	9/4/77	2.10	0.380	2,964	26.0	26.0	6.8	6.8
182	9/6/77	2.10	0.365	1,937	27.0	27.0	6.8	6.7
183	9/7/77	2.50	0.375	2,223	26.5	26.0	6.8	6.8
184	9/8/77	2.10	0.370	1,908	27.0	26.0	7.3	7.3
185	9/9/77	2.30	0.380	2,422	25.0	25.0	6.5	6.5
186	9/10/77	2.70	0.400	2,193	25.0	25.0	7.4	7.4
187	9/11/77	2.30	0.390	2,165	25.0	25.0	7.0	6.8
188	9/12/77	2.10	0.350	2,023	25.0	25.0	6.2	6.2
189	9/13/77	2.40	0.405	2,052	26.0	25.0	7.0	7.1
190	9/14/77	2.10	0.375	1,938	26.0	25.0	7.0	7.0
191	9/15/77	2.20	0.375	1,424	26.0	25.0	6.9	7.0
192	9/16/77	2.20	0.375	2,478	26.0	25.0	7.6	7.5
193	9/17/77	3.00	0.390	2,166	24.6	24.0	7.4	7.3
194	9/18/77	2.40	0.425	1,424	24.5	25.0	7.2	7.1
195	9/19/77	2.20	0.420	1,453	25.0	25.0	7.4	7.4

continued.

TABLE A-1. (continued)

Day	Date	Flow Plant	RBC (mgd)	RBC Sludge (gpd)	Temp. °C RBC In	Temp. °C RBC Out	pH RBC In	pH RBC Out
196	9/20/77	2.50	0.425	1,795	25.0	25.0	7.3	7.3
197	9/21/77	3.10	0.845	-	24.0	24.0	7.2	7.2
198	9/22/77	2.30	0.370	2,791	24.0	23.0	7.2	7.2
199	9/23/77	2.30	0.355	2,165	24.0	24.0	6.6	6.5
200	9/24/77	-	-	-	-	-	-	-
201	9/25/77	-	-	-	-	-	-	-
202	9/26/77	-	-	-	-	-	-	-
203	9/27/77	-	-	-	-	-	-	-
204	9/28/77	-	-	-	-	-	-	-
205	9/29/77	-	-	-	-	-	-	-
206	9/30/77	-	-	-	-	-	-	-
207	10/1/77	-	-	-	-	-	-	-
208	10/2/77	-	-	-	-	-	-	-
209	10/3/77	-	-	-	-	-	-	-
210	10/4/77	2.50	0.355	1,852	24.0	22.0	7.1	7.2
211	10/5/77	2.30	0.353	1,481	-	-	6.8	6.7
212	10/6/77	2.40	0.355	2,108	22.0	22.0	-	-
213	10/7/77	2.50	0.378	2,108	22.0	22.0	6.7	6.7
214	10/8/77	2.40	0.570	-	20.0	20.0	7.4	7.5
215	10/9/77	3.10	0.570	-	18.0	18.0	7.3	7.3
216	10/10/77	4.00	0.330	2,649	21.0	20.0	6.8	6.8
217	10/11/77	3.10	0.435	1,767	21.0	20.0	6.2	-
218	10/12/77	2.60	0.390	1,563	21.0	21.0	6.7	6.4
219	10/13/77	2.70	0.470	2,763	21.0	19.0	6.5	6.8
220	10/14/77	2.70	0.435	2,164	20.0	19.0	7.3	7.3
221	10/15/77	3.80	0.465	2,707	17.0	17.0	7.2	7.2
222	10/16/77	3.20	0.415	1,653	20.0	20.0	7.0	7.0
223	10/17/77	2.90	0.420	1,909	20.0	19.0	7.0	6.8
224	10/18/77	3.00	0.435	2,593	20.0	19.0	7.0	7.3
225	10/19/77	2.50	0.460	2,906	21.0	20.0	7.0	7.3
226	10/20/77	3.20	0.585	2,279	18.0	17.0	6.9	7.0
227	10/21/77	4.10	0.605	941	19.0	18.0	7.6	7.7
228	10/22/77	3.20	0.560	2,905	20.0	19.0	8.2	7.7
229	10/23/77	2.70	0.708	2,648	19.0	18.0	7.2	7.3
230	10/24/77	2.40	0.678	2,192	20.0	19.0	7.1	7.1
231	10/25/77	2.60	0.523	2,450	20.0	19.0	7.2	7.3
232	10/26/77	2.00	0.553	2,622	21.0	20.0	7.5	7.4
233	10/27/77	2.80	0.553	1,852	20.0	20.0	8.2	7.5
234	10/28/77	2.50	0.555	1,682	21.0	20.0	7.8	7.5
235	10/29/77	2.60	0.572	2,252	19.0	19.0	8.1	7.8

continued.

TABLE A-1. (continued)

Day	Date	Flow Plant	RBC (mgd)	RBC Sludge (gpd)	Temp. °C RBC In	Temp. °C RBC Out	pH RBC In	pH RBC Out
236	10/30/77	2.60	0.540	1,537	19.0	19.0	7.5	7.6
237	10/31/77	2.30	0.580	4,188	20.0	19.0	7.6	7.5
238	11/1/77	2.50	0.615	3,981	20.0	19.0	7.6	7.5
239	11/2/77	2.20	0.545	4,160	20.0	20.0	7.5	7.5
240	11/3/77	2.30	0.580	3,363	21.0	20.0	7.3	7.4
241	11/4/77	2.30	0.580	3,363	21.0	20.0	7.3	7.4
242	11/5/77	2.50	0.585	2,736	20.0	20.0	7.0	7.0
243	11/6/77	2.40	0.570	2,820	19.0	19.0	7.6	7.6
244	11/7/77	2.30	0.560	3,505	-	-	6.9	7.1
245	11/8/77	5.40	0.595	-	-	-	-	-
246	11/9/77	5.80	0.555	-	17.0	16.0	-	-
247	11/10/77	3.10	0.595	1,737	18.0	17.0	7.5	7.5
248	11/11/77	4.00	0.595	3,134	18.0	18.0	7.4	7.5
249	11/12/77	3.60	0.608	1,908	18.0	17.0	7.8	7.6
250	11/13/77	3.00	0.595	1,767	18.0	17.0	7.2	7.2
251	11/14/77	2.60	0.588	2,536	18.0	17.0	7.4	7.2
252	11/15/77	2.60	0.605	3,219	18.0	18.0	7.6	7.5
253	11/16/77	2.40	0.605	4,303	18.0	17.0	7.3	7.3
254	11/17/77	3.00	0.590	5,243	18.0	18.0	7.6	7.4
255	11/18/77	3.00	0.615	2,392	19.0	17.0	7.7	7.4
256	11/19/77	2.70	0.625	2,650	17.0	17.0	7.4	7.0
257	11/20/77	2.50	0.540	912	17.0	16.0	7.5	7.7
258	11/21/77	2.20	0.560	2,508	18.0	17.0	7.6	7.4
259	11/22/77	2.40	0.585	2,395	18.0	17.0	7.8	7.9
260	11/23/77	2.70	0.750	3,191	15.0	14.0	7.2	7.2
261	11/24/77	3.00	0.455	-	-	-	-	-
262	11/25/77	2.60	0.340	-	-	-	-	-
263	11/26/77	3.10	0.345	-	-	-	-	-
264	11/27/77	3.50	0.345	-	-	-	-	-
265	11/28/77	2.70	0.335	-	-	-	-	-
266	11/29/77	-	-	-	-	-	-	-
267	11/30/77	-	-	-	-	-	-	-
268	12/1/77	-	-	-	-	-	-	-
269	12/2/77	-	-	-	-	-	-	-
270	12/3/77	-	-	-	-	-	-	-
271	12/4/77	-	-	-	-	-	-	-
272	12/5/77	-	-	-	-	-	-	-
273	12/6/77	3.50	0.415	2,279	15.0	14.0	7.7	7.4
274	12/7/77	3.30	0.435	1,681	15.0	15.0	7.2	7.2
275	12/8/77	3.00	0.420	1,767	16.0	15.0	7.3	7.2

continued.

TABLE A-1. (continued)

					Temp. °C		pH	
				RBC	RBC		RBC	
Day	Date	Flow Plant	RBC (mgd)	Sludge (gpd)	In	Out	In	Out
276	12/9/77	2.80	0.390	1,909	13.0	14.0	7.0	7.2
277	12/10/77	3.10	0.165	2,450	14.0	13.0	-	-
278	12/11/77	2.60	0.270	2,165	-	-	-	-
279	12/12/77	2.50	0.385	2,108	15.0	14.0	7.6	7.4
280	12/13/77	2.70	0.395	2,450	15.0	14.0	7.9	-
281	12/14/77	2.50	0.405	2,052	15.0	14.0	7.4	7.4
282	12/15/77	4.10	0.413	1,369	14.0	14.0	8.7	8.2
283	12/16/77	3.50	0.393	1,852	14.0	13.0	7.2	7.2
284	12/17/77	3.20	0.430	2,166	14.0	13.0	7.2	7.2
285	12/18/77	2.90	0.400	1,680	14.0	12.0	7.9	7.6
286	12/19/77	3.80	0.395	1,396	12.0	11.0	7.3	7.1
287	12/20/77	4.00	0.403	2,079	13.0	12.0	7.3	7.2
288	12/21/77	3.60	0.400	1,369	-	-	7.5	7.2
289	12/22/77	5.30	0.110	-	-	-	-	-
290	12/23/77	-	-	-	-	-	-	-
291	12/24/77	32.50	0.470	-	-	-	-	-
292	12/25/77	3.40	0.465	-	-	-	-	-
293	12/26/77	3.10	0.435	-	-	-	-	-
294	12/27/77	2.70	0.455	-	-	-	-	-
295	12/28/77	2.70	0.435	-	-	-	-	-
296	12/29/77	2.80	0.455	-	-	-	-	-
297	12/30/77	2.80	0.650	-	-	-	-	-
298	12/31/77	2.90	0.270	-	-	-	-	-
299	1/1/78	2.90	0.440	-	-	-	-	-
300	1/2/78	2.50	0.435	-	-	-	-	-
301	1/3/78	2.40	0.425	2,164	13.0	12.0	7.6	7.4
302	1/4/78	2.30	0.415	455	13.0	13.0	7.5	-
303	1/5/78	2.10	0.390	3,534	13.0	12.0	7.4	7.6
304	1/6/78	2.30	0.420	2,677	14.0	13.0	8.5	7.9
305	1/7/78	2.30	0.400	1,880	13.0	12.0	8.2	7.7
306	1/8/78	2.10	0.395	1,738	11.0	12.0	7.4	7.3
307	1/9/78	3.10	0.385	2,223	12.0	12.0	7.2	7.2
308	1/10/78	3.60	0.405	1,881	13.0	12.0	7.4	7.2
309	1/11/78	3.10	0.400	1,937	13.0	12.0	7.5	-
310	1/12/78	2.70	0.410	2,508	13.0	13.0	7.6	7.5
311	1/13/78	2.40	0.420	2,251	13.0	12.0	7.6	7.6
312	1/14/78	3.10	0.385	1,396	9.0	9.0	7.5	7.4
313	1/15/78	4.00	0.195	1,880	11.0	11.0	7.1	6.9
314	1/16/78	2.80	0.380	1,708	12.0	11.0	7.4	7.3
315	1/17/78	2.60	0.398	2,051	-	-	7.0	7.0

continued.

TABLE A-1. (continued)

		Flow		RBC	Temp. °C RBC		pH RBC	
Day	Date	Plant	RBC (mgd)	Sludge (gpd)	In	Out	In	Out
316	1/18/78	1.80	0.219	2,251	9.0	10.0	7.0	6.9
317	1/19/78	3.80	0.403	2,222	11.0	10.0	7.2	7.0
318	1/20/78	3.30	0.413	1,882	-	-	7.4	7.4
319	1/21/78	3.10	0.400	1,744	11.0	10.0	7.0	6.8
320	1/22/78	3.00	0.400	1,560	10.0	10.0	6.8	6.8
321	1/23/78	2.70	0.380	2,621	12.0	12.0	7.0	7.0
322	1/24/78	2.60	0.400	3,414	12.0	11.0	7.2	7.2
323	1/25/78	2.60	0.350	2,590	-	-	7.1	7.0
324	1/26/78	5.20	0.295	1,452	7.0	7.0	8.1	7.1
325	1/27/78	7.00	0.305	1,253	9.0	7.0	7.1	7.1
326	1/28/78	4.10	0.335	1,766	10.0	9.0	7.6	7.6
327	1/29/78	3.10	0.305	1,197	10.0	9.0	7.4	7.4
328	1/30/78	2.10	0.290	2,535	11.0	10.0	7.5	7.4
329	1/31/78	2.90	0.320	1,509	11.0	10.0	7.5	7.4
330	2/1/78	2.80	0.305	1,994	11.0	11.0	7.4	7.4
331	2/2/78	2.60	0.310	1,482	12.0	10.0	7.4	7.3
332	2/3/78	8.40	0.390	1,994	12.0	11.0	7.4	7.3
333	2/4/78	2.50	0.495	2,677	11.0	9.0	7.4	7.3
334	2/5/78	1.20	0.490	1,966	10.0	9.0	6.8	6.9
335	2/6/78	2.10	0.465	1,994	-	-	7.0	7.0
336	2/7/78	2.50	0.495	2,222	-	-	6.8	6.8
337	2/8/78	2.60	0.515	2,963	12.0	11.0	7.0	6.9
338	2/9/78	2.70	0.460	3,048	12.0	11.0	6.9	7.1
339	2/10/78	2.70	0.475	3,029	12.0	11.0	7.2	7.1
340	2/11/78	2.90	0.430	3,076	11.0	10.0	7.9	7.6
341	2/12/78	2.60	0.430	2,309	10.0	9.0	7.5	7.5
342	2/13/78	2.30	0.468	2,706	12.0	11.0	7.3	7.2
343	2/14/78	2.60	0.363	3,562	12.0	12.0	7.2	7.2
344	2/15/78	2.60	0.385	2,907	12.0	11.0	7.2	7.2
345	2/16/78	2.50	0.390	3,021	12.0	12.0	7.1	7.1
346	2/17/78	2.50	0.385	3,334	12.0	12.0	7.1	7.1
347	2/18/78	2.40	0.390	3,190	11.0	10.0	7.6	7.7
348	2/19/78	2.50	0.400	2,073	11.0	10.0	6.9	7.0
349	2/20/78	2.50	0.420	2,193	-	-	-	-
350	2/21/78	2.40	0.405	3,674	12.0	11.0	7.6	7.5
351	2/22/78	2.40	0.395	2,507	12.0	11.0	8.2	8.0
352	2/23/78	2.50	0.405	2,222	12.0	10.0	7.4	7.2
353	2/24/78	2.60	-	-	12.0	11.0	7.6	7.3

continued.

TABLE A-1. (continued)

		Dissolved Oxygen (mg/l)						
Day	Date	Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
1	3/9/77	8.4	7.0	4.6	4.6	4.3	4.0	3.8
2	3/10/77	8.6	7.0	3.8	4.0	3.6	3.4	3.4
3	3/11/77	7.9	7.0	4.6	4.5	4.0	3.0	2.6
4	3/12/77	7.4	7.2	4.6	4.8	3.8	2.6	2.2
5	3/13/77	8.0	7.4	4.8	4.8	4.6	3.8	3.4
6	3/14/77	8.6	8.5	4.6	4.6	4.4	4.2	4.2
7	3/15/77	7.4	7.6	4.0	3.6	3.8	3.4	2.9
8	3/16/77	8.5	8.4	4.4	4.1	3.9	3.7	3.4
9	3/17/77	6.8	6.6	4.2	3.3	2.9	2.9	2.9
10	3/18/77	-	-	-	-	-	-	-
11	3/19/77	7.6	6.4	4.2	4.2	3.9	3.9	3.5
12	3/20/77	8.2	7.5	4.6	4.6	4.4	4.4	4.2
13	3/21/77	7.6	6.7	3.8	4.1	3.6	3.5	3.5
14	3/22/77	-	-	-	-	-	-	-
15	3/23/77	9.1	8.7	6.8	7.1	7.2	6.6	5.9
16	3/24/77	8.1	7.3	5.6	6.4	6.8	6.6	6.1
17	3/25/77	7.5	6.7	5.7	6.3	6.6	6.2	5.6
18	3/26/77	7.8	8.0	6.0	5.8	6.0	6.0	5.6
19	3/27/77	7.2	6.2	5.4	5.8	6.0	5.4	5.4
20	3/28/77	9.7	7.6	5.0	5.2	5.7	5.9	5.9
21	3/29/77	7.2	6.3	3.8	3.8	4.2	4.8	4.4
22	3/30/77	7.2	5.6	3.3	3.0	3.3	3.1	3.2
23	3/31/77	5.8	5.3	3.3	3.5	3.2	3.3	2.8
24	4/1/77	6.6	6.0	3.3	3.2	3.6	3.4	3.0
25	4/2/77	7.0	7.2	3.8	3.2	3.0	2.6	1.4
26	4/3/77	9.2	9.1	6.0	5.8	6.0	5.4	4.4
27	4/4/77	6.5	6.0	3.5	3.5	4.1	4.1	3.2
28	4/5/77	-	-	-	-	-	-	-
29	4/6/77	8.1	7.6	5.0	4.5	4.6	4.5	3.7
30	4/7/77	7.4	6.6	4.8	4.8	5.6	4.9	4.5
31	4/8/77	-	-	-	-	-	-	-
32	4/9/77	-	-	-	-	-	-	-
33	4/10/77	-	-	-	-	-	-	-
34	4/11/77	6.0	5.4	2.9	2.4	2.7	2.6	2.3
35	4/12/77	6.2	5.0	2.4	2.3	2.7	2.4	1.6
36	4/13/77	5.9	4.8	2.8	2.6	2.6	2.0	1.0
37	4/14/77	5.9	5.3	2.6	2.5	2.9	2.0	1.1
38	4/15/77	6.0	5.0	3.0	2.9	3.1	2.2	1.6
39	4/16/77	5.6	5.0	3.0	2.9	3.1	2.2	1.2
40	4/17/77	4.9	4.6	3.2	2.0	2.8	2.6	0.8

continued.

TABLE A-1. (continued)

Day	Date	Dissolved Oxygen (mg/l) Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
41	4/18/77	5.1	4.2	2.8	1.9	1.6	1.0	0.8
42	4/19/77	5.5	4.1	2.5	2.0	1.5	1.0	0.8
43	4/20/77	5.6	4.6	3.0	2.0	1.7	1.2	0.7
44	4/21/77	4.9	3.9	2.3	1.6	1.4	0.8	0.3
45	4/22/77	5.1	3.2	2.4	1.7	1.5	1.1	0.4
46	4/23/77	5.2	4.4	3.8	3.6	3.4	2.2	0.4
47	4/24/77	5.0	3.8	3.6	3.4	3.4	2.6	0.4
48	4/25/77	5.9	4.9	3.5	2.6	2.1	1.9	1.6
49	4/26/77	-	-	-	-	-	-	-
50	4/27/77	6.0	5.0	3.3	2.3	2.1	1.8	1.5
51	4/28/77	6.6	5.9	4.0	2.9	2.4	1.7	0.7
52	4/29/77	-	4.2	-	-	-	2.0	-
53	4/30/77	6.0	5.1	3.0	2.8	3.0	2.8	1.0
54	5/1/77	6.0	4.3	3.4	3.2	3.0	2.6	1.9
55	5/2/77	5.7	4.1	2.5	1.9	2.1	1.2	0.7
56	5/3/77	5.7	5.1	2.5	1.9	2.1	1.2	0.3
57	5/4/77	6.3	5.1	3.3	2.1	1.5	1.0	0.7
58	5/5/77	7.9	7.5	3.9	2.7	2.1	1.5	1.1
59	5/6/77	7.0	8.2	5.2	4.4	-	3.8	4.2
60	5/7/77	-	-	-	-	-	-	-
61	5/8/77	7.8	7.2	5.1	1.2	1.4	4.1	5.2
62	5/9/77	6.4	5.8	4.0	3.2	2.8	2.8	2.8
63	5/10/77	6.4	5.4	3.8	2.4	2.0	1.5	1.9
64	5/11/77	6.9	5.2	3.6	2.8	2.4	2.2	2.4
65	5/12/77	5.3	4.8	3.6	2.8	2.2	1.8	1.8
66	5/13/77	5.2	4.8	3.2	2.4	2.6	2.4	2.2
67	5/14/77	5.4	5.0	4.0	3.4	3.2	3.0	2.0
68	5/15/77	6.0	4.8	3.8	3.6	3.8	3.4	2.2
69	5/16/77	4.6	2.6	2.2	1.8	1.6	1.2	1.0
70	5/17/77	5.2	3.1	2.2	1.4	1.0	0.6	0.8
71	5/18/77	4.6	2.4	2.2	1.5	1.4	1.2	0.8
72	5/19/77	5.0	2.2	2.2	1.4	1.0	0.6	0.4
73	5/20/77	4.1	2.2	1.8	1.2	0.8	0.4	0.2
74	5/21/77	3.8	2.2	2.2	1.2	1.6	1.6	0.6
75	5/22/77	4.3	2.4	1.8	1.2	1.0	0.8	0.6
76	5/23/77	4.6	1.6	1.2	1.4	1.4	1.0	1.2
77	5/24/77	3.9	-	-	-	-	-	0.6
78	5/25/77	5.5	2.4	2.0	1.6	1.2	0.8	0.4
79	5/26/77	4.8	2.6	2.2	1.8	1.4	0.6	0.5
80	5/27/77	4.6	2.2	2.0	1.6	1.4	1.0	0.8

continued.

TABLE A-1. (continued)

		Dissolved Oxygen (mg/l)						
Day	Date	Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
81	5/28/77	4.6	2.0	2.0	1.6	1.5	1.0	0.8
82	5/29/77	4.4	1.4	3.4	3.8	3.4	2.4	1.2
83	5/30/77	3.0	2.2	2.2	2.2	2.2	2.2	2.2
84	5/31/77	4.2	2.8	1.8	1.4	1.0	0.6	0.6
85	6/1/77	4.0	2.2	1.4	1.0	0.8	0.8	0.8
86	6/2/77	4.6	1.2	1.2	1.2	1.0	0.8	0.6
87	6/3/77	5.0	1.6	1.4	1.0	1.0	0.8	0.8
88	6/4/77	3.2	2.4	1.8	1.6	1.2	0.8	1.0
89	6/5/77	3.8	1.6	1.2	1.0	1.0	0.8	0.6
90	6/6/77	4.0	1.6	1.6	1.4	1.0	0.8	0.6
91	6/7/77	4.4	3.2	2.2	1.8	1.4	1.0	0.6
92	6/8/77	4.6	1.4	1.4	1.2	0.8	0.6	0.6
93	6/9/77	-	-	-	-	-	-	-
94	6/10/77	-	-	-	-	-	-	-
95	6/11/77	5.2	4.2	3.2	2.8	2.2	1.0	0.8
96	6/12/77	5.0	2.4	2.0	1.8	1.4	1.2	1.0
97	6/13/77	4.6	2.2	2.2	1.4	1.0	0.8	0.8
98	6/14/77	4.8	2.8	2.2	1.8	1.4	0.6	0.6
99	6/15/77	4.2	1.6	1.2	1.0	0.6	0.4	0.4
100	6/16/77	4.2	1.0	1.0	0.8	0.6	0.4	0.4
101	6/17/77	4.4	2.0	2.0	1.6	1.0	0.4	0.4
102	6/18/77	4.8	2.2	2.0	1.2	1.2	0.6	1.0
103	6/19/77	-	-	-	-	-	-	-
104	6/20/77	4.6	1.8	1.8	1.4	1.2	1.2	1.2
105	6/21/77	4.6	1.8	1.8	1.4	1.2	1.2	1.2
106	6/22/77	5.0	2.2	1.4	1.4	1.2	0.4	0.4
107	6/23/77	4.6	1.8	1.4	1.2	1.0	1.0	1.0
108	6/24/77	3.8	1.8	1.2	1.0	0.8	0.4	0.2
109	6/25/77	5.0	3.8	2.2	2.0	1.4	0.6	0.6
110	6/26/77	5.2	3.8	2.0	1.8	1.6	0.4	0.4
111	6/27/77	4.2	1.4	1.2	1.2	1.0	0.6	1.0
112	6/28/77	4.4	2.2	1.2	1.0	0.8	0.6	0.6
113	6/29/77	5.2	3.4	1.6	1.4	1.0	0.4	0.8
114	6/30/77	3.2	0.8	0.6	0.6	0.4	0.2	0.4
115	7/1/77	3.0	0.8	0.8	0.8	0.6	0.4	0.4
116	7/2/77	-	-	-	-	-	-	-
117	7/3/77	-	-	-	-	-	-	-
118	7/4/77	-	-	-	-	-	-	-
119	7/5/77	-	-	-	-	-	-	-
120	7/6/77	3.2	1.0	0.8	0.8	0.6	0.4	0.4

continued.

TABLE A-1. (continued)

		Dissolved Oxygen (mg/l)						
Day	Date	Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
121	7/7/77	3.8	1.6	0.8	0.8	0.8	0.2	0.0
122	7/8/77	5.2	3.2	1.2	1.2	1.0	0.2	0.4
123	7/9/77	4.4	1.2	2.0	1.2	1.4	0.8	0.6
124	7/10/77	3.8	1.4	1.0	1.0	0.8	0.6	0.8
125	7/11/77	3.8	2.4	1.0	1.0	0.8	0.4	0.4
126	7/12/77	4.3	2.2	0.8	0.8	0.6	0.2	0.4
127	7/13/77	4.4	1.4	0.8	0.8	0.6	0.4	0.4
128	7/14/77	3.4	2.6	1.0	1.0	0.8	0.6	1.2
129	7/15/77	4.6	2.8	1.4	1.6	1.4	1.2	1.2
130	7/16/77	3.0	1.2	0.8	0.8	0.8	0.6	0.6
131	7/17/77	3.0	1.0	0.4	0.6	0.6	0.4	0.2
132	7/18/77	4.0	1.4	0.6	0.8	0.4	0.4	0.4
133	7/19/77	0.8	1.2	0.6	0.8	0.4	0.4	0.4
134	7/20/77	3.8	3.2	0.8	0.8	0.6	0.4	0.2
135	7/21/77	2.6	0.4	0.2	0.2	0.2	0.1	0.2
136	7/22/77	1.6	0.6	0.4	0.4	0.2	0.2	0.6
137	7/23/77	4.0	1.6	0.6	0.4	0.4	0.8	0.8
138	7/24/77	3.0	1.0	0.8	0.8	0.8	0.6	0.8
139	7/25/77	4.6	0.4	0.4	0.6	0.4	0.4	0.4
140	7/26/77	4.0	0.3	0.3	0.4	0.5	0.2	0.2
141	7/27/77	3.0	0.2	0.3	0.4	0.2	0.4	0.2
142	7/28/77	-	-	-	-	-	-	-
143	7/29/77	3.2	1.0	0.8	0.8	0.8	0.8	0.2
144	7/30/77	2.2	0.6	0.8	0.8	0.8	0.6	0.6
145	7/31/77	2.2	1.0	0.6	0.6	0.6	0.3	0.2
146	8/1/77	2.6	0.8	0.8	0.6	0.4	0.4	0.4
147	8/2/77	3.6	1.8	1.2	1.0	0.4	0.2	0.6
148	8/3/77	1.2	1.3	0.6	0.6	0.4	0.2	0.8
149	8/4/77	3.2	0.4	0.4	0.3	0.3	0.4	0.4
150	8/5/77	1.4	0.4	0.4	0.4	0.4	0.6	0.4
151	8/6/77	3.4	0.6	0.6	0.6	0.8	0.6	0.4
152	8/7/77	2.2	0.4	0.4	1.6	2.0	0.8	0.4
153	8/8/77	3.6	1.8	1.2	1.2	1.2	0.6	0.4
154	8/9/77	3.2	1.6	0.8	0.6	0.6	0.8	0.6
155	8/10/77	3.2	1.0	0.6	0.6	0.6	0.8	0.4
156	8/11/77	3.6	1.2	0.6	0.6	0.4	0.6	0.6
157	8/12/77	-	-	-	-	-	-	-
158	8/13/77	3.4	1.8	1.0	0.8	1.0	1.2	0.6
159	8/14/77	4.0	1.4	1.0	0.8	0.8	1.0	0.4
160	8/15/77	4.0	2.6	4.2	4.4	4.4	3.8	2.0

continued.

TABLE A-1. (continued)

Day	Date	Dissolved Oxygen (mg/l)						
		Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
161	8/16/77	4.0	1.6	1.0	1.0	1.0	1.0	0.4
162	8/17/77	4.2	1.0	0.7	0.4	0.3	0.3	0.3
163	8/18/77	4.0	0.8	0.8	0.5	0.2	0.2	0.2
164	8/19/77	3.9	1.1	0.7	0.7	0.4	0.4	0.4
165	8/20/77	4.6	2.8	1.2	0.8	0.6	0.8	0.6
166	8/21/77	3.2	1.0	0.8	1.2	1.6	1.8	0.8
167	8/22/77	6.2	4.8	3.2	2.4	1.8	1.6	0.6
168	8/23/77	3.0	2.2	0.6	0.6	0.6	0.9	0.3
169	8/24/77	4.2	1.8	0.8	0.2	0.2	0.3	0.2
170	8/25/77	3.6	3.4	1.2	1.2	1.2	1.4	0.6
171	8/26/77	6.0	4.2	2.0	1.6	1.4	1.8	1.6
172	8/27/77	3.8	1.2	0.8	0.6	0.4	0.8	0.6
173	8/28/77	2.8	1.0	0.6	0.4	0.4	0.8	0.2
174	8/29/77	4.5	2.3	0.6	0.4	0.4	0.6	0.2
175	8/30/77	?.?	? ?	?.?	?.?	?.?	?.?	0.6
176	8/31/77	4.2	4.3	5.7	5.8	5.7	5.7	0.6
177	9/1/77	5.0	1.8	1.1	1.4	1.0	1.6	0.6
178	9/2/77	6.0	2.2	1.2	0.8	0.6	1.0	0.6
179	9/3/77	3.0	1.2	1.2	1.4	1.8	2.4	0.6
180	9/4/77	2.8	0.8	1.2	1.4	1.6	2.0	0.6
181	9/4/77	3.0	1.0	1.0	0.8	1.0	0.8	0.6
182	9/6/77	4.6	4.2	1.6	0.8	0.8	0.6	0.6
183	9/7/77	3.2	1.0	1.8	1.2	1.2	1.4	1.4
184	9/8/77	3.4	1.2	1.0	0.8	0.6	1.0	0.4
185	9/9/77	5.2	0.6	0.8	0.8	0.6	0.8	0.6
186	9/10/77	4.2	2.6	1.5	1.8	2.2	2.2	0.8
187	9/11/77	3.8	0.8	1.0	1.2	1.8	2.0	0.6
188	9/12/77	2.8	0.6	0.8	0.8	0.8	1.0	0.4
189	9/13/77	2.5	1.4	1.0	0.8	0.8	1.0	0.2
190	9/14/77	2.5	1.4	0.8	0.8	1.0	1.4	0.4
191	9/15/77	2.5	1.4	0.8	0.8	0.6	1.0	0.3
192	9/16/77	2.5	1.4	1.0	0.8	0.7	1.0	0.4
193	9/17/77	4.6	3.6	1.4	1.0	1.0	1.4	0.4
194	9/18/77	3.2	1.0	0.8	0.8	1.0	1.4	0.4
195	9/19/77	2.6	1.4	0.6	1.0	0.8	1.0	0.3
196	9/20/77	2.5	1.4	0.8	1.0	1.0	1.0	0.3
197	9/21/77	2.5	1.6	0.8	0.6	0.6	0.3	0.3
198	9/22/77	4.0	1.6	0.8	0.6	1.0	1.4	0.6
199	9/23/77	2.6	1.4	0.6	0.6	0.6	1.0	0.4
200	9/24/77	-	-	-	-	-	-	-

continued.

TABLE A-1. (continued)

		Dissolved Oxygen (mg/1)						
Day	Date	Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
201	9/25/77	-	-	-	-	-	-	-
202	9/26/77	-	-	-	-	-	-	-
203	9/27/77	-	-	-	-	-	-	-
204	9/28/77	-	-	-	-	-	-	-
205	9/29/77	-	-	-	-	-	-	-
206	9/30/77	-	-	-	-	-	-	-
207	10/1/77	-	-	-	-	-	-	-
208	10/2/77	-	-	-	-	-	-	-
209	10/3/77	-	-	-	-	-	-	-
210	10/4/77	3.2	1.8	1.0	0.8	1.4	1.8	0.2
211	10/5/77	-	-	-	-	-	-	-
212	10/6/77	6.0	3.5	1.8	1.2	1.0	1.4	0.6
213	10/7/77	2.6	2.8	1.6	1.4	1.4	2.0	0.4
214	10/8/77	5.4	3.6	2.2	1.4	1.4	2.2	0.4
215	10/9/77	-	-	-	-	-	-	-
216	10/10/77	5.1	4.6	2.6	1.5	1.2	1.5	0.4
217	10/11/77	5.2	3.1	2.4	1.6	1.4	2.4	0.4
218	10/12/77	4.3	3.0	2.6	2.6	2.2	3.0	0.5
219	10/13/77	4.4	2.0	1.0	1.0	1.4	2.4	0.8
220	10/14/77	4.6	3.0	2.0	1.4	1.4	2.4	0.6
221	10/15/77	7.6	6.8	4.6	3.8	4.0	4.2	3.0
222	10/16/77	5.2	2.6	2.8	2.4	2.2	2.8	4.2
223	10/17/77	1.0	3.4	2.0	1.6	1.6	2.0	1.2
224	10/18/77	5.2	2.0	1.6	1.6	1.6	2.4	0.8
225	10/19/77	4.2	3.0	2.2	1.8	2.0	2.4	0.4
226	10/20/77	7.4	7.0	4.2	2.2	2.0	2.0	2.8
227	10/21/77	6.2	5.8	3.6	2.4	2.2	2.6	2.6
228	10/22/77	5.4	5.0	3.2	2.4	1.8	1.8	1.0
229	10/23/77	4.0	2.8	2.2	2.0	1.8	1.8	1.4
230	10/24/77	4.0	1.6	1.8	0.8	0.8	0.8	1.2
231	10/25/77	4.6	2.8	2.0	1.4	1.0	1.4	0.8
232	10/26/77	5.6	2.8	2.0	1.4	0.8	0.8	0.6
233	10/27/77	5.2	3.4	2.8	2.0	0.8	0.8	0.8
234	10/28/77	4.4	2.6	2.0	1.2	0.8	0.8	0.4
235	10/29/77	5.0	3.4	2.8	2.0	1.6	1.6	0.6
236	10/30/77	3.8	3.0	2.4	1.8	1.2	1.6	0.4
237	10/31/77	4.0	3.0	2.0	1.4	0.8	0.8	0.5
238	11/1/77	4.2	2.8	2.0	1.6	0.8	0.8	0.8
239	11/2/77	4.0	3.4	2.4	1.4	0.8	0.6	0.4
240	11/3/77	3.8	2.2	2.2	1.0	0.6	0.4	0.4

continued.

TABLE A-1. (continued)

		Dissolved Oxygen (mg/l)						
Day	Date	Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
241	11/4/77	3.8	2.2	2.2	1.0	0.6	0.4	0.6
242	11/5/77	4.2	1.0	2.4	1.4	1.4	1.4	2.6
243	11/6/77	4.0	2.8	2.2	1.6	1.6	1.6	1.0
244	11/7/77	-	-	-	-	-	-	-
245	11/8/77	-	-	-	-	-	-	-
246	11/9/77	5.2	5.6	5.0	5.0	4.2	4.2	4.2
247	11/10/77	5.4	4.2	5.0	4.2	4.4	4.5	4.1
248	11/11/77	4.8	5.4	4.6	4.0	3.8	3.4	3.4
249	11/12/77	4.4	4.8	4.2	3.6	3.2	3.0	3.0
250	11/13/77	2.4	6.2	5.0	4.2	4.0	4.2	4.0
251	11/14/77	5.4	5.2	3.6	3.0	2.0	2.2	1.6
252	11/15/77	5.4	4.6	3.5	2.4	2.0	2.2	1.8
253	11/16/77	5.4	4.4	3.2	1.8	1.0	1.4	0.8
254	11/17/77	5.8	4.8	3.8	2.8	1.6	1.6	0.8
255	11/18/77	5.6	5.0	3.8	2.8	1.8	2.2	1.8
256	11/19/77	4.2	4.6	3.8	3.6	3.8	3.6	0.2
257	11/20/77	5.2	5.2	4.0	3.6	2.8	2.6	2.4
258	11/21/77	4.8	4.2	3.6	2.4	1.6	1.8	1.2
259	11/22/77	1.2	3.8	2.8	2.0	1.2	1.4	0.6
260	11/23/77	6.2	6.6	5.6	5.0	4.4	4.2	2.8
261	11/24/77	-	-	-	-	-	-	-
262	11/25/77	-	-	-	-	-	-	-
263	11/26/77	-	-	-	-	-	-	-
264	11/27/77	-	-	-	-	-	-	-
265	11/28/77	-	-	-	-	-	-	-
266	11/29/77	-	-	-	-	-	-	-
267	11/30/77	-	-	-	-	-	-	-
268	12/1/77	-	-	-	-	-	-	-
269	12/2/77	-	-	-	-	-	-	-
270	12/3/77	-	-	-	-	-	-	-
271	12/4/77	-	-	-	-	-	-	-
272	12/5/77	-	-	-	-	-	-	-
273	12/6/77	6.6	6.6	6.4	4.6	4.6	3.8	3.6
274	12/7/77	7.0	6.6	5.2	4.4	4.4	4.0	3.8
275	12/8/77	6.4	6.0	4.6	3.4	2.6	2.8	1.0
276	12/9/77	8.2	4.2	6.4	5.8	5.4	5.2	7.6
277	12/10/77	4.8	5.8	5.2	5.0	5.4	5.4	3.6
278	12/11/77	-	-	-	-	-	-	-
279	12/12/77	5.4	5.2	4.5	3.6	3.0	3.2	3.2
280	12/13/77	4.8	5.2	4.0	3.4	2.6	2.8	2.4

continued.

TABLE A-1. (continued)

Day	Date	Dissolved Oxygen (mg/l) Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
281	12/14/77	5.0	4.8	4.0	3.2	2.6	2.8	2.4
282	12/15/77	4.0	5.2	4.4	3.8	3.2	3.2	3.2
283	12/16/77	3.8	5.2	4.6	3.6	3.4	3.2	3.2
284	12/17/77	3.8	3.2	4.2	3.6	3.4	3.8	3.0
285	12/18/77	4.4	3.0	-	-	-	-	-
286	12/19/77	3.4	4.8	4.4	4.0	4.0	4.1	3.8
287	12/20/77	4.2	5.4	4.8	4.4	3.8	4.0	3.8
288	12/21/77	-	-	-	-	-	-	-
289	12/22/77	-	-	-	-	-	-	-
290	12/23/77	-	-	-	-	-	-	-
291	12/24/77	-	-	-	-	-	-	-
292	12/25/77	-	-	-	-	-	-	-
293	12/26/77	-	-	-	-	-	-	-
294	12/27/77	-	-	-	-	-	-	-
295	12/28/77	-	-	-	-	-	-	-
296	12/29/77	-	-	-	-	-	-	-
297	12/30/77	-	-	-	-	-	-	-
298	12/31/77	-	-	-	-	-	-	-
299	1/1/78	-	-	-	-	-	-	-
300	1/2/78	-	-	-	-	-	-	-
301	1/3/78	4.6	4.6	4.4	3.4	3.4	3.2	3.4
302	1/4/78	5.2	4.8	4.2	3.4	3.2	3.4	2.4
303	1/5/78	3.4	3.8	3.4	2.8	2.8	2.8	1.6
304	1/6/78	3.6	4.0	3.4	3.2	2.8	3.0	1.2
305	1/7/78	4.2	4.6	4.2	4.0	3.2	3.0	2.0
306	1/8/78	6.2	6.2	5.4	4.4	4.2	4.0	4.0
307	1/9/78	3.8	4.2	4.4	4.2	3.6	3.6	2.6
308	1/10/78	1.2	2.0	2.1	2.0	1.6	1.6	1.6
309	1/11/78	1.2	2.4	2.2	2.0	1.6	1.6	1.2
310	1/12/78	1.2	1.6	2.2	1.8	1.6	1.6	1.6
311	1/13/78	2.8	2.8	2.8	2.8	2.6	2.6	2.4
312	1/14/78	2.4	4.4	3.0	3.0	2.8	2.8	4.4
313	1/15/78	1.0	1.4	2.2	2.0	2.4	2.6	1.8
314	1/16/78	2.0	2.8	2.8	2.6	2.8	2.8	2.0
315	1/17/78	-	-	-	-	-	-	-
316	1/18/78	9.2	9.0	7.8	7.8	7.0	6.6	3.2
317	1/19/78	8.8	9.6	7.6	6.4	5.8	5.0	5.1
318	1/20/78	-	-	-	-	-	-	-
319	1/21/78	8.2	8.2	5.4	5.2	5.0	5.0	5.0
320	1/22/78	7.6	8.2	6.2	5.8	6.8	7.0	5.2

continued.

TABLE A-1. (continued)

		Dissolved Oxygen (mg/1)						
Day	Date	Raw	RBC In	Stg 1	Stg 2	Stg 3	Stg 4	RBC Out
321	1/23/78	8.2	6.6	4.6	3.8	3.2	3.4	3.0
322	1/24/78	2.6	7.0	4.6	3.8	3.8	3.8	2.8
323	1/25/78	-	-	-	-	-	-	-
324	1/26/78	10.2	10.1	9.4	9.7	8.6	8.3	8.2
325	1/27/78	8.8	8.2	6.7	7.3	7.2	6.8	6.8
326	1/28/78	9.0	8.2	7.2	6.8	7.2	6.6	5.2
327	1/29/78	8.6	8.2	6.8	6.8	6.8	6.6	5.6
328	1/30/78	8.8	8.0	7.0	6.8	6.8	6.8	6.0
329	1/31/78	7.4	6.8	4.4	4.2	4.2	4.4	4.2
330	2/1/78	8.1	7.8	5.0	4.4	4.5	4.4	3.6
331	2/2/78	8.0	6.4	4.0	3.8	4.4	4.5	4.2
332	2/3/78	8.4	7.5	5.1	3.6	3.6	3.4	2.8
333	2/4/78	8.6	7.2	6.0	5.6	5.0	4.8	4.4
334	2/5/78	9.0	8.2	7.0	6.0	5.4	5.4	1.6
335	2/6/78	-	-	-	-	-	-	-
336	2/7/78	-	-	-	-	-	-	-
337	2/8/78	5.4	6.2	5.0	4.8	3.6	3.4	2.8
338	2/9/78	6.2	5.8	5.0	3.8	3.8	3.6	2.8
339	2/10/78	8.0	6.3	5.0	3.5	2.8	2.4	2.4
340	2/11/78	8.4	8.0	4.0	3.8	3.2	3.0	4.0
341	2/12/78	7.2	6.0	4.0	3.8	3.2	3.0	4.0
342	2/13/78	9.6	7.8	6.2	4.9	4.4	4.2	3.6
343	2/14/78	8.6	8.1	6.0	4.2	3.6	3.2	2.0
344	2/15/78	7.8	8.0	6.0	5.0	4.4	4.0	2.2
345	2/16/78	9.2	8.2	5.8	5.4	4.0	3.8	3.2
346	2/17/78	7.4	6.9	5.6	4.0	3.2	3.0	2.6
347	2/18/78	8.2	8.2	7.2	6.0	4.5	5.2	2.4
348	2/19/78	8.6	8.0	6.8	6.0	5.6	5.0	4.4
349	2/20/78	-	-	-	-	-	-	-
350	2/21/78	8.2	7.4	6.2	4.8	4.0	3.6	3.2
351	2/22/78	9.4	7.0	5.4	3.8	3.2	3.0	2.8
352	2/23/78	7.8	6.6	5.2	4.0	3.4	3.2	3.2
353	2/24/78	6.6	6.2	5.0	4.4	3.8	3.7	3.4

continued.

TABLE A-1. (continued)

		BOD_5-T (mg/l)			BOD_5-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
1	3/9/77	106	109	34	52	61	22
2	3/10/77	190	160	34	109	84	29
3	3/11/77	151	183	45	76	91	35
4	3/12/77	123	140	33	82	91	19
5	3/13/77	130	142	38	87	86	25
6	3/14/77	72	70	15	22	26	13
7	3/15/77	108	90	18	46	48	15
8	3/16/77	97	88	16	43	37	11
9	3/17/77	124	126	23	74	98	25
10	3/18/77	93	87	20	49	56	14
11	3/19/77	87	87	30	-	-	-
12	3/20/77	-	-	-	-	-	-
13	3/21/77	108	119	26	57	77	14
14	3/22/77	112	118	22	-	-	-
15	3/23/77	50	51	14	28	29	15
16	3/24/77	80	62	13	-	-	-
17	3/25/77	64	-	14	39	-	10
18	3/26/77	71	-	17	50	-	9
19	3/27/77	-	84	17	-	62	10
20	3/28/77	-	84	11	-	24	-
21	3/29/77	121	112	13	84	64	12
22	3/30/77	111	112	9	-	-	-
23	3/31/77	93	101	16	50	33	5
24	4/1/77	59	72	18	29	38	4
25	4/2/77	105	120	19	86	71	10
26	4/3/77	87	93	10	37	41	10
27	4/4/77	111	100	10	58	43	9
28	4/5/77	141	82	16	87	75	12
29	4/6/77	51	-	-	42	-	-
30	4/7/77	127	117	20	63	63	11
31	4/8/77	-	-	-	-	-	-
32	4/9/77	-	-	-	-	-	-
33	4/10/77	-	-	-	-	-	-
34	4/11/77	169	135	22	62	72	8
35	4/12/77	117	102	13	68	71	8
36	4/13/77	195	159	-	42	41	19
37	4/14/77	171	159	27	-	-	22
38	4/15/77	132	117	15	41	50	9
39	4/16/77	-	126	19	-	156	17
40	4/17/77	-	135	24	-	81	16

continued.

TABLE A-1. (continued)

		BOD_5-T (mg/l)			BOD_5-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
41	4/18/77	156	137	18	77	86	9
42	4/19/77	195	191	39	123	129	33
43	4/20/77	183	191	25	188	210	22
44	4/21/77	225	197	30	129	150	25
45	4/22/77	109	102	17	61	60	12
46	4/23/77	-	100	18	105	82	15
47	4/24/77	162	195	21	108	86	20
48	4/25/77	144	144	15	68	94	15
49	4/26/77	171	146	27	100	114	18
50	4/27/77	168	165	26	108	104	76
51	4/28/77	207	183	25	153	144	28
52	4/29/77	129	142	24	-	96	13
53	4/30/77	100	-	26	64	-	24
54	5/1/77	158	138	23	92	67	26
55	5/2/77	161	170	18	87	92	13
56	5/3/77	174	153	50	138	108	25
57	5/4/77	185	162	30	149	113	31
58	5/5/77	234	221	20	180	-	63
59	5/6/77	128	114	25	71	94	27
60	5/7/77	-	-	-	-	-	-
61	5/8/77	72	-	17	42	-	16
62	5/9/77	111	121	15	46	89	16
63	5/10/77	110	102	16	57	63	17
64	5/11/77	147	150	29	107	96	27
65	5/12/77	147	159	21	122	111	20
66	5/13/77	128	123	16	102	92	17
67	5/14/77	153	147	20	-	-	-
68	5/15/77	104	122	14	-	-	-
69	5/16/77	137	138	21	-	-	-
70	5/17/77	131	155	16	-	-	-
71	5/18/77	153	168	50	-	-	-
72	5/19/77	131	129	53	-	-	-
73	5/20/77	204	162	60	-	-	-
74	5/21/77	176	153	67	-	-	-
75	5/22/77	126	110	38	-	-	-
76	5/23/77	162	141	47	-	-	-
77	5/24/77	143	137	55	-	-	-
78	5/25/77	98	95	36	45	43	25
79	5/26/77	171	149	58	90	85	34
80	5/27/77	-	155	44	-	-	28

continued.

TABLE A-1. (continued)

		BOD$_5$-T (mg/l)			BOD$_5$-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
81	5/28/77	143	145	60	-	-	-
82	5/29/77	159	140	45	-	-	-
83	5/30/77	144	135	18	-	55	15
84	5/31/77	148	124	43	-	65	20
85	6/1/77	159	144	72	-	63	25
86	6/2/77	179	120	54	-	65	24
87	6/3/77	155	144	74	-	80	39
88	6/4/77	119	159	78	-	-	-
89	6/5/77	116	108	45	-	-	-
90	6/6/77	137	129	48	117	72	30
91	6/7/77	-	-	-	-	-	-
92	6/8/77	-	-	-	-	-	-
93	6/9/77	183	185	25	83	86	32
94	6/10/77	68	68	26	23	21	16
95	6/11/77	-	-	-	-	-	-
96	6/12/77	102	119	42	60	62	25
97	6/13/77	123	96	30	65	52	28
98	6/14/77	123	147	20	70	116	37
99	6/15/77	168	158	51	90	93	39
100	6/16/77	124	128	57	79	78	24
101	6/17/77	170	146	66	92	105	30
102	6/18/77	136	177	53	63	66	14
103	6/19/77	-	-	-	-	-	-
104	6/20/77	153	143	53	63	58	19
105	6/21/77	201	174	98	71	92	46
106	6/22/77	135	153	86	61	69	38
107	6/23/77	136	128	47	55	57	28
108	6/24/77	162	146	52	80	72	28
109	6/25/77	120	148	56	-	-	-
110	6/26/77	118	138	57	-	-	-
111	6/27/77	153	180	53	104	102	24
112	6/28/77	183	190	86	108	115	56
113	6/29/77	153	152	66	84	84	48
114	6/30/77	166	189	114	108	105	57
115	7/1/77	112	123	57	-	99	42
116	7/2/77	-	-	-	-	-	-
117	7/3/77	-	-	-	-	-	-
118	7/4/77	-	-	-	-	-	-
119	7/5/77	-	-	-	-	-	-
120	7/6/77	180	152	48	-	-	-

continued.

TABLE A-1. (continued)

Day	Date	BOD_5-T (mg/l) Raw	BOD_5-T (mg/l) RBC In	BOD_5-T (mg/l) RBC Out	BOD_5-S (mg/l) Raw	BOD_5-S (mg/l) RBC In	BOD_5-S (mg/l) RBC Out
121	7/7/77	192	134	58	-	-	-
122	7/8/77	189	170	64	-	-	-
123	7/9/77	-	-	-	-	-	-
124	7/10/77	-	-	-	-	-	-
125	7/11/77	-	-	-	-	-	-
126	7/12/77	-	-	-	-	-	-
127	7/13/77	-	-	-	-	-	-
128	7/14/77	573	120	15	-	-	-
129	7/15/77	144	140	51	54	102	31
130	7/16/77	-	164	72	-	-	-
131	7/17/77	132	126	34	-	-	-
132	7/18/77	104	118	21	-	-	-
133	7/19/77	168	173	46	101	108	34
134	7/20/77	96	122	29	65	68	25
135	7/21/77	132	156	48	-	114	35
136	7/22/77	159	144	53	-	103	26
137	7/23/77	165	105	24	-	-	-
138	7/24/77	154	143	31	-	-	-
139	7/25/77	98	-	20	53	43	21
140	7/26/77	146	144	44	85	94	30
141	7/27/77	117	105	31	-	73	23
142	7/28/77	119	144	31	-	80	16
143	7/29/77	-	-	-	-	-	-
144	7/30/77	146	158	44	-	-	-
145	7/31/77	111	114	22	-	-	-
146	8/1/77	110	102	18	-	48	9
147	8/2/77	138	132	29	62	66	16
148	8/3/77	143	159	37	-	86	21
149	8/4/77	185	146	32	-	109	17
150	8/5/77	161	138	30	100	94	17
151	8/6/77	111	131	21	-	-	-
152	8/7/77	120	95	21	-	-	-
153	8/8/77	108	146	13	-	80	11
154	8/9/77	102	113	38	60	71	33
155	8/10/77	131	126	26	71	63	20
156	8/11/77	122	122	31	109	116	18
157	8/12/77	92	129	28	-	115	35
158	8/13/77	138	128	19	-	-	-
159	8/14/77	120	62	13	-	-	-
160	8/15/77	126	-	11	52	-	9

continued.

TABLE A-1. (continued)

Day	Date	BOD_5-T (mg/l) Raw	BOD_5-T (mg/l) RBC In	BOD_5-T (mg/l) RBC Out	BOD_5-S (mg/l) Raw	BOD_5-S (mg/l) RBC In	BOD_5-S (mg/l) RBC Out
161	8/16/77	113	152	63	57	82	46
162	8/17/77	102	112	22	77	74	20
163	8/18/77	129	146	27	-	115	30
164	8/19/77	130	141	33	94	90	25
165	8/20/77	104	130	23	-	-	-
166	8/21/77	107	120	19	-	-	-
167	8/22/77	130	120	22	-	113	17
168	8/23/77	95	100	19	59	81	16
169	8/24/77	117	120	26	-	72	12
170	8/25/77	79	110	20	85	88	20
171	8/26/77	142	170	36	115	145	25
172	8/27/77	140	165	31	-	-	-
173	8/28/77	161	115	15	-	-	-
174	8/29/77	118	122	9	-	75	10
175	8/30/77	150	135	20	-	93	16
176	8/31/77	147	135	38	111	122	40
177	9/1/77	-	-	-	-	-	-
178	9/2/77	-	-	-	-	-	-
179	9/3/77	-	-	-	-	-	-
180	9/4/77	-	-	-	-	-	-
181	9/4/77	-	-	-	-	-	-
182	9/6/77	-	-	-	-	-	-
183	9/7/77	-	-	-	-	-	-
184	9/8/77	-	-	-	-	-	-
185	9/9/77	-	-	-	-	-	-
186	9/10/77	-	-	-	-	-	-
187	9/11/77	-	-	-	-	-	-
188	9/12/77	76	83	17	-	93	19
189	9/13/77	128	131	38	-	113	24
190	9/14/77	153	223	41	127	169	28
191	9/15/77	144	153	26	-	121	24
192	9/16/77	189	201	35	-	149	30
193	9/17/77	117	117	19	-	-	-
194	9/18/77	108	117	18	-	-	-
195	9/19/77	122	124	16	-	91	20
196	9/20/77	132	149	28	-	120	28
197	9/21/77	-	-	-	-	-	-
198	9/22/77	224	209	73	152	164	60
199	9/23/77	156	-	25	98	-	11
200	9/24/77	-	-	-	-	-	-

continued.

TABLE A-1. (continued)

Day	Date	BOD$_5$-T (mg/l) Raw	BOD$_5$-T (mg/l) RBC In	BOD$_5$-T (mg/l) RBC Out	BOD$_5$-S (mg/l) Raw	BOD$_5$-S (mg/l) RBC In	BOD$_5$-S (mg/l) RBC Out
201	9/25/77	-	-	-	-	-	-
202	9/26/77	-	-	-	-	-	-
203	9/27/77	-	-	-	-	-	-
204	9/28/77	-	-	-	-	-	-
205	9/29/77	-	-	-	-	-	-
206	9/30/77	-	-	-	-	-	-
207	10/1/77	-	-	-	-	-	-
208	10/2/77	-	-	-	-	-	-
209	10/3/77	-	-	-	-	-	-
210	10/4/77	171	193	33	-	-	-
211	10/5/77	159	160	26	-	-	-
212	10/6/77	161	185	30	-	127	22
213	10/7/77	177	197	44	-	-	-
214	10/8/77	155	-	-	-	-	-
215	10/9/77	-	-	-	-	-	-
216	10/10/77	57	64	6	-	-	-
217	10/11/77	134	135	27	-	-	18
218	10/12/77	-	135	145	-	-	-
219	10/13/77	159	251	95	-	171	72
220	10/14/77	140	183	33	-	-	-
221	10/15/77	132	-	23	-	-	-
222	10/16/77	84	123	12	-	-	-
223	10/17/77	138	149	19	-	85	16
224	10/18/77	195	164	41	-	121	43
225	10/19/77	179	124	46	-	92	19
226	10/20/77	178	180	56	-	144	21
227	10/21/77	113	105	29	-	57	16
228	10/22/77	120	132	22	-	-	-
229	10/23/77	122	117	28	-	-	-
230	10/24/77	158	140	25	-	73	24
231	10/25/77	249	209	66	-	113	46
232	10/26/77	282	206	70	-	119	31
233	10/27/77	137	138	40	-	88	26
234	10/28/77	183	105	56	-	107	28
235	10/29/77	195	171	65	-	93	41
236	10/30/77	178	136	41	-	58	30
237	10/31/77	175	138	38	-	32	18
238	11/1/77	186	174	45	-	56	22
239	11/2/77	210	131	45	-	113	33
240	11/3/77	186	150	50	-	88	22

continued.

TABLE A-1. (continued)

		BOD$_5$-T (mg/l)			BOD$_5$-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
241	11/4/77	165	179	58	-	96	24
242	11/5/77	109	122	34	-	-	-
243	11/6/77	110	113	32	-	-	-
244	11/7/77	-	116	31	-	86	32
245	11/8/77	-	-	-	-	-	-
246	11/9/77	-	-	-	-	-	-
247	11/10/77	69	56	18	-	63	31
248	11/11/77	111	109	43	74	84	34
249	11/12/77	72	78	17	-	-	-
250	11/13/77	74	78	23	-	-	-
251	11/14/77	97	95	35	-	74	22
252	11/15/77	168	139	57	-	100	30
253	11/16/77	219	208	82	-	139	62
254	11/17/77	194	161	44	-	111	40
255	11/18/77	170	170	73	92	123	42
256	11/19/77	130	137	44	-	-	-
257	11/20/77	128	117	38	-	-	-
258	11/21/77	101	128	37	-	71	32
259	11/22/77	171	147	45	88	97	38
260	11/23/77	222	192	60	-	136	49
261	11/24/77	-	-	-	-	-	-
262	11/25/77	-	-	-	-	-	-
263	11/26/77	-	-	-	-	-	-
264	11/27/77	-	-	-	-	-	-
265	11/28/77	-	-	-	-	-	-
266	11/29/77	-	-	-	-	-	-
267	11/30/77	-	-	-	-	-	-
268	12/1/77	-	-	-	-	-	-
269	12/2/77	-	-	-	-	-	-
270	12/3/77	-	-	-	-	-	-
271	12/4/77	-	-	-	-	-	-
272	12/5/77	-	-	-	-	-	-
273	12/6/77	119	144	31	77	73	20
274	12/7/77	137	167	40	75	89	23
275	12/8/77	116	134	35	81	76	16
276	12/9/77	81	143	38	-	70	17
277	12/10/77	122	-	-	-	-	-
278	12/11/77	-	-	-	-	-	-
279	12/12/77	146	134	20	-	78	11
280	12/13/77	150	197	-	-	110	-

continued.

TABLE A-1. (continued)

		BOD_5-T (mg/l)			BOD_5-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
281	12/14/77	152	141	39	–	89	22
282	12/15/77	113	119	31	–	55	22
283	12/16/77	141	141	22	94	94	23
284	12/17/77	122	137	21	–	–	–
285	12/18/77	129	135	25	–	–	–
286	12/19/77	114	107	15	–	60	13
287	12/20/77	102	168	12	–	74	13
288	12/21/77	131	167	19	–	67	15
289	12/22/77	–	–	–	–	–	–
290	12/23/77	–	–	–	–	–	–
291	12/24/77	–	–	–	–	–	–
292	12/25/77	–	–	–	–	–	–
293	12/26/77	–	–	–	–	–	–
294	12/27/77	–	–	–	–	–	–
295	12/28/77	–	–	–	–	–	–
296	12/29/77	–	–	–	–	–	–
297	12/30/77	–	–	–	–	–	–
298	12/31/77	–	–	–	–	–	–
299	1/1/78	–	–	–	–	–	–
300	1/2/78	–	–	–	–	–	–
301	1/3/78	134	182	38	98	96	23
302	1/4/78	257	206	–	153	129	–
303	1/5/78	159	174	49	–	119	29
304	1/6/78	164	159	35	–	106	27
305	1/7/78	186	180	34	–	–	–
306	1/8/78	135	152	34	–	–	–
307	1/9/78	123	146	23	–	86	15
308	1/10/78	107	98	20	–	69	18
309	1/11/78	189	161	–	60	91	–
310	1/12/78	174	168	38	–	112	20
311	1/13/78	92	158	32	–	108	23
312	1/14/78	99	144	26	–	–	–
313	1/15/78	87	96	17	–	–	–
314	1/16/78	131	119	19	–	87	16
315	1/17/78	146	108	26	–	82	14
316	1/18/78	242	221	27	59	135	21
317	1/19/78	87	104	20	–	62	24
318	1/20/78	74	98	10	–	59	13
319	1/21/78	96	119	16	–	–	–
320	1/22/78	92	126	32	–	–	–

continued.

TABLE A-1. (continued)

		BOD$_5$-T (mg/1)			BOD$_5$-S (mg/1)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
321	1/23/78	192	260	24	-	92	22
322	1/24/78	252	213	25	-	137	20
323	1/25/78	168	185	31	-	108	21
324	1/26/78	101	72	17	-	52	12
325	1/27/78	77	57	10	-	45	11
326	1/28/78	66	83	12	-	-	-
327	1/29/78	60	66	10	-	-	-
328	1/30/78	132	125	16	34	53	12
329	1/31/78	126	50	29	-	42	16
330	2/1/78	219	155	33	-	94	29
331	2/2/78	102	168	17	-	85	11
332	2/3/78	196	174	33	67	104	24
333	2/4/78	164	195	135	-	-	-
334	2/5/78	159	188	53	-	-	-
335	2/6/78	137	174	46	57	90	26
336	2/7/78	185	183	42	-	87	30
337	2/8/78	216	167	45	-	85	39
338	2/9/78	222	171	49	-	119	37
339	2/10/78	210	162	45	-	84	34
340	2/11/78	129	170	46	-	-	-
341	2/12/78	125	150	46	-	-	-
342	2/13/78	201	192	45	69	107	36
343	2/14/78	242	243	41	-	113	29
344	2/15/78	227	225	46	-	125	34
345	2/16/78	182	209	41	-	99	32
346	2/17/78	341	203	50	-	87	29
347	2/18/78	157	173	20	-	-	-
348	2/19/78	105	153	30	-	-	-
349	2/20/78	-	-	-	-	-	-
350	2/21/78	201	213	53	99	109	29
351	2/22/78	302	261	102	-	136	81
352	2/23/78	237	242	55	-	116	34
353	2/24/78	210	218	56	-	99	38

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
1	3/9/77	250	306	141	168	187	129
2	3/10/77	-	-	-	-	-	-
3	3/11/77	396	388	82	136	120	82
4	3/12/77	-	-	-	-	-	-
5	3/13/77	-	-	-	-	-	-
6	3/14/77	184	205	110	110	134	73
7	3/15/77	-	-	-	-	-	-
8	3/16/77	235	155	111	114	98	51
9	3/17/77	-	-	-	-	-	-
10	3/18/77	250	224	108	148	102	74
11	3/19/77	-	-	-	-	-	-
12	3/20/77	-	-	-	-	-	-
13	3/21/77	-	-	-	-	-	-
14	3/22/77	-	-	-	-	-	-
15	3/23/77	-	-	-	-	-	-
16	3/24/77	-	-	-	-	-	-
17	3/25/77	-	-	-	-	-	-
18	3/26/77	-	-	-	-	-	-
19	3/27/77	-	-	-	-	-	-
20	3/28/77	-	236	60	-	121	58
21	3/29/77	-	-	-	-	-	-
22	3/30/77	-	-	-	-	-	-
23	3/31/77	-	-	-	-	-	-
24	4/1/77	237	242	55	133	114	48
25	4/2/77	-	-	-	-	-	-
26	4/3/77	-	-	-	-	-	-
27	4/4/77	298	171	38	106	92	33
28	4/5/77	-	-	-	-	-	-
29	4/6/77	201	-	-	66	-	-
30	4/7/77	-	-	-	-	-	-
31	4/8/77	-	-	-	-	-	-
32	4/9/77	-	-	-	-	-	-
33	4/10/77	-	-	-	-	-	-
34	4/11/77	328	270	58	124	146	42
35	4/12/77	-	-	-	-	-	-
36	4/13/77	326	302	78	200	218	72
37	4/14/77	252	238	73	176	180	69
38	4/15/77	278	254	70	166	180	58
39	4/16/77	-	-	-	-	-	-
40	4/17/77	-	-	-	-	-	-

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
41	4/18/77	310	292	79	136	138	58
42	4/19/77	-	-	-	-	-	-
43	4/20/77	322	286	91	202	208	81
44	4/21/77	446	316	80	200	186	70
45	4/22/77	228	224	65	124	128	52
46	4/23/77	-	-	-	-	-	-
47	4/24/77	-	-	-	-	-	-
48	4/25/77	304	292	70	140	176	58
49	4/26/77	-	-	-	-	-	-
50	4/27/77	312	266	76	204	184	71
51	4/28/77	-	-	-	-	-	-
52	4/29/77	332	268	77	200	218	72
53	4/30/77	-	-	-	-	-	-
54	5/1/77	-	-	-	-	-	-
55	5/2/77	316	264	144	270	182	142
56	5/3/77	-	-	-	-	-	-
57	5/4/77	384	286	86	200	196	89
58	5/5/77	412	330	105	232	258	105
59	5/6/77	316	274	72	190	192	68
60	5/7/77	-	-	-	-	-	-
61	5/8/77	-	-	-	-	-	-
62	5/9/77	188	226	49	108	130	45
63	5/10/77	-	-	-	-	-	-
64	5/11/77	320	304	70	170	176	67
65	5/12/77	436	158	80	184	130	69
66	5/13/77	320	261	73	204	228	74
67	5/14/77	-	-	-	-	-	-
68	5/15/77	-	-	-	-	-	-
69	5/16/77	376	292	63	-	-	-
70	5/17/77	296	319	89	-	-	-
71	5/18/77	328	287	116	-	-	-
72	5/19/77	356	256	131	-	-	-
73	5/20/77	368	277	132	-	-	-
74	5/21/77	-	-	-	-	-	-
75	5/22/77	-	-	-	-	-	-
76	5/23/77	348	336	117	-	-	-
77	5/24/77	432	314	150	-	-	-
78	5/25/77	220	202	102	93	93	75
79	5/26/77	204	210	96	93	82	58
80	5/27/77	408	362	126	-	-	97

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
81	5/28/77	-	-	-	-	-	-
82	5/29/77	-	-	-	-	-	-
83	5/30/77	396	240	75	-	200	46
84	5/31/77	-	215	106	-	172	76
85	6/1/77	324	285	150	-	120	92
86	6/2/77	244	229	102	-	96	62
87	6/3/77	264	165	123	106	96	75
88	6/4/77	-	-	-	-	-	-
89	6/5/77	-	-	-	-	-	-
90	6/6/77	256	223	96	194	205	69
91	6/7/77	-	-	-	-	-	-
92	6/8/77	-	-	-	-	-	-
93	6/9/77	-	346	100	181	181	100
94	6/10/77	128	136	64	66	53	48
95	6/11/77	-	-	-	-	-	-
96	6/12/77	-	-	-	-	-	-
97	6/13/77	320	277	115	160	133	71
98	6/14/77	436	378	186	178	200	109
99	6/15/77	384	346	186	176	197	118
100	6/16/77	392	325	144	176	184	97
101	6/17/77	284	266	124	170	162	116
102	6/18/77	-	-	-	-	-	-
103	6/19/77	-	-	-	-	-	-
104	6/20/77	316	285	116	208	-	89
105	6/21/77	548	413	284	269	237	160
106	6/22/77	444	389	236	275	288	173
107	6/23/77	392	317	148	173	187	88
108	6/24/77	236	275	98	157	155	70
109	6/25/77	-	-	-	-	-	-
110	6/26/77	-	-	-	-	-	-
111	6/27/77	344	291	136	205	181	85
112	6/28/77	372	323	166	205	205	162
113	6/29/77	372	352	178	211	221	121
114	6/30/77	361	330	159	213	219	116
115	7/1/77	316	243	112	-	152	77
116	7/2/77	-	-	-	-	-	-
117	7/3/77	-	-	-	-	-	-
118	7/4/77	-	-	-	-	-	-
119	7/5/77	-	-	-	-	-	-
120	7/6/77	-	323	130	-	187	74

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	**Date**	**Raw**	**In**	**Out**	**Raw**	**In**	**Out**
121	7/7/77	-	320	195	-	138	100
122	7/8/77	-	280	118	-	189	101
123	7/9/77	-	-	-	-	-	-
124	7/10/77	-	-	-	-	-	-
125	7/11/77	-	295	132	-	188	112
126	7/12/77	-	288	152	-	202	101
127	7/13/77	-	236	128	-	143	110
128	7/14/77	-	252	123	-	214	104
129	7/15/77	309	295	112	194	171	97
130	7/16/77	-	-	-	-	-	-
131	7/17/77	-	-	-	-	-	-
132	7/18/77	-	-	-	-	-	-
133	7/19/77	-	402	146	-	-	121
134	7/20/77	260	285	112	173	-	95
135	7/21/77	368	373	126	-	221	104
136	7/22/77	412	357	122	-	245	116
137	7/23/77	-	-	-	-	-	108
138	7/24/77	-	-	-	-	-	-
139	7/25/77	288	245	74	184	184	59
140	7/26/77	-	186	112	-	179	98
141	7/27/77	356	269	104	-	176	100
142	7/28/77	-	-	-	-	-	-
143	7/29/77	-	-	-	-	-	-
144	7/30/77	-	-	-	-	-	-
145	7/31/77	-	-	-	-	-	-
146	8/1/77	352	296	86	219	171	68
147	8/2/77	-	307	94	-	193	71
148	8/3/77	376	316	98	-	201	90
149	8/4/77	336	268	90	-	175	80
150	8/5/77	346	267	98	222	152	82
151	8/6/77	-	-	-	-	-	-
152	8/7/77	-	-	-	-	-	-
153	8/8/77	268	163	83	-	128	66-76?
154	8/9/77	-	256	142	-	189	116
155	8/10/77	468	288	88	179	195	96
156	8/11/77	588	293	136	264	219	85
157	8/12/77	544	344	130	280	224	98
158	8/13/77	-	-	-	-	-	-
159	8/14/77	-	-	-	-	-	-
160	8/15/77	284	-	108	160	-	78

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
161	8/16/77	-	392	192	-	216	126
162	8/17/77	248	411	127	179	221	102
163	8/18/77	360	352	86	-	240	112
164	8/19/77	292	287	106	160	163	133
165	8/20/77	-	-	-	-	-	-
166	8/21/77	-	-	-	-	-	-
167	8/22/77	338	307	107	-	192	78
168	8/23/77	-	275	90	-	189	73
169	8/24/77	236	152	96	-	180	92
170	8/25/77	208	300	99	117	216	112
171	8/26/77	304	319	109	235	264	126
172	8/27/77	-	-	-	-	-	-
173	8/28/77	-	-	-	-	-	-
174	8/29/77	414	301	103	-	217	58
175	8/30/77	366	308	94	-	203	85
176	8/31/77	370	344	147	232	220	119
177	9/1/77	446	415	332	260	287	213
178	9/2/77	384	309	164	183	180	124
179	9/3/77	-	-	-	-	-	-
180	9/4/77	-	-	-	-	-	-
181	9/4/77	-	-	-	-	-	-
182	9/6/77	-	-	-	-	-	-
183	9/7/77	460	349	152	-	189	100
184	9/8/77	588	344	121	187	195	90
185	9/9/77	448	424	153	256	256	120
186	9/10/77	-	-	-	-	-	-
187	9/11/77	-	-	-	-	-	-
188	9/12/77	388	288	75	-	173	65
189	9/13/77	456	365	138	-	217	96
190	9/14/77	284	405	140	192	227	94
191	9/15/77	328	288	108	-	245	116
192	9/16/77	382	332	126	-	255	125
193	9/17/77	-	-	-	-	-	-
194	9/18/77	-	-	-	-	-	-
195	9/19/77	400	307	76	-	220	87
196	9/20/77	496	349	109	-	213	108
197	9/21/77	-	-	-	-	-	-
198	9/22/77	380	324	137	225	245	106
199	9/23/77	264	-	74	189	-	75
200	9/24/77	-	-	-	-	-	-

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
201	9/25/77	-	-	-	-	-	-
202	9/26/77	-	-	-	-	-	-
203	9/27/77	-	-	-	-	-	-
204	9/28/77	-	-	-	-	-	-
205	9/29/77	-	-	-	-	-	-
206	9/30/77	-	-	-	-	-	-
207	10/1/77	-	-	-	-	-	-
208	10/2/77	-	-	-	-	-	-
209	10/3/77	-	-	-	-	-	-
210	10/4/77	454	415	100	-	-	-
211	10/5/77	286	312	80	-	-	-
212	10/6/77	420	347	100	-	250	81
213	10/7/77	324	349	96	-	-	-
214	10/8/77	-	-	-	-	-	-
215	10/9/77	-	-	-	-	-	-
216	10/10/77	182	199	51	-	-	-
217	10/11/77	294	307	82	-	-	84
218	10/12/77	351	279	388	-	-	-
219	10/13/77	346	381	172	-	252	106
220	10/14/77	236	309	78	-	-	-
221	10/15/77	-	-	-	-	-	-
222	10/16/77	-	-	-	-	-	-
223	10/17/77	320	280	76	-	224	79
224	10/18/77	340	336	114	-	203	106
225	10/19/77	-	128	72	-	128	63
226	10/20/77	224	328	102	-	211	88
227	10/21/77	252	272	80	-	173	77
228	10/22/77	-	-	-	-	-	-
229	10/23/77	-	-	-	-	-	-
230	10/24/77	316	245	72	-	149	44
231	10/25/77	456	363	116	-	192	95
232	10/26/77	516	395	158	-	235	123
233	10/27/77	224	299	110	-	184	86
234	10/28/77	290	335	101	-	209	101
235	10/29/77	-	-	-	-	-	-
236	10/30/77	-	-	-	-	-	-
237	10/31/77	356	376	104	-	-	-
238	11/1/77	348	268	98	-	128	66
239	11/2/77	596	316	108	-	181	104
240	11/3/77	356	284	131	-	178	102

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
241	11/4/77	480	268	101	-	216	105
242	11/5/77	-	-	-	-	-	-
243	11/6/77	-	-	-	-	-	-
244	11/7/77	-	301	116	-	117	91
245	11/8/77	-	-	-	-	-	-
246	11/9/77	-	-	-	-	-	-
247	11/10/77	262	170	85	-	137	89
248	11/11/77	284	243	117	196	185	95
249	11/12/77	-	-	-	-	-	-
250	11/13/77	-	-	-	-	-	-
251	11/14/77	320	273	137	-	181	88
252	11/15/77	461	309	144	-	212	101
253	11/16/77	488	351	146	-	241	121
254	11/17/77	374	311	123	-	225	109
255	11/18/77	344	337	163	235	272	144
256	11/19/77	-	-	-	-	-	-
257	11/20/77	-	-	-	-	-	-
258	11/21/77	384	257	98	-	192	102
259	11/22/77	364	309	104	200	220	109
260	11/23/77	438	311	125	-	219	113
261	11/24/77	-	-	-	-	-	-
262	11/25/77	-	-	-	-	-	-
263	11/26/77	-	-	-	-	-	-
264	11/27/77	-	-	-	-	-	-
265	11/28/77	-	-	-	-	-	-
266	11/29/77	-	-	-	-	-	-
267	11/30/77	-	-	-	-	-	-
268	12/1/77	-	-	-	-	-	-
269	12/2/77	-	-	-	-	-	-
270	12/3/77	-	-	-	-	-	-
271	12/4/77	-	-	-	-	-	-
272	12/5/77	-	-	-	-	-	-
273	12/6/77	320	491	120	155	181	72
274	12/7/77	292	336	85	-	197	61
275	12/8/77	336	304	93	173	157	71
276	12/9/77	304	349	125	-	226	89
277	12/10/77	-	-	-	-	-	-
278	12/11/77	-	-	-	-	-	-
279	12/12/77	284	243	54	-	157	45
280	12/13/77	428	405	-	-	208	-

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
281	12/14/77	444	344	92	-	-	77
282	12/15/77	308	237	76	-	112	76
283	12/16/77	268	275	61	162	165	64
284	12/17/77	-	-	-	-	-	-
285	12/18/77	-	-	-	-	-	-
286	12/19/77	252	234	49	-	144	59
287	12/20/77	312	272	72	-	173	81
288	12/21/77	288	315	80	-	133	68
289	12/22/77	-	-	-	-	-	-
290	12/23/77	-	-	-	-	-	-
291	12/24/77	-	-	-	-	-	-
292	12/25/77	-	-	-	-	-	-
293	12/26/77	-	-	-	-	-	-
294	12/27/77	-	-	-	-	-	-
295	12/28/77	-	-	-	-	-	-
296	12/29/77	-	-	-	-	-	-
297	12/30/77	-	-	-	-	-	-
298	12/31/77	-	-	-	-	-	-
299	1/1/78	-	-	-	-	-	-
300	1/2/78	-	-	-	-	-	-
301	1/3/78	304	309	76	168	168	80
302	1/4/78	464	355	-	270	214	-
303	1/5/78	484	336	113	-	203	93
304	1/6/78	384	320	105	-	213	92
305	1/7/78	-	-	-	-	-	-
306	1/8/78	-	-	-	-	-	-
307	1/9/78	260	248	75	-	128	61
308	1/10/78	288	188	87	-	155	88
309	1/11/78	400	275	-	123	176	-
310	1/12/78	424	304	111	-	261	116
311	1/13/78	276	336	115	-	200	71
312	1/14/78	-	-	-	-	-	-
313	1/15/78	-	-	-	-	-	-
314	1/16/78	276	253	71	-	179	74
315	1/17/78	296	208	80	-	125	52
316	1/18/78	492	421	64	93	213	61
317	1/19/78	196	203	63	-	131	65
318	1/20/78	132	109	31	-	59	30
319	1/21/78	-	-	-	-	-	-
320	1/22/78	-	-	-	-	-	-

continued.

TABLE A-1. (continued)

		COD-T (mg/l)			COD-S (mg/l)		
			RBC			RBC	
Day	Date	Raw	In	Out	Raw	In	Out
321	1/23/78	176	149	39	67	80	32
322	1/24/78	232	197	36	-	125	36
323	1/25/78	341	343	81	-	209	80
324	1/26/78	376	224	44	-	99	48
325	1/27/78	164	157	35	-	72	41
326	1/28/78	-	-	-	-	-	-
327	1/29/78	-	-	-	-	-	-
328	1/30/78	256	235	55	107	147	49
329	1/31/78	484	448	60	-	181	69
330	2/1/78	520	144	88	-	189	66
331	2/2/78	565	466	47	-	160	58
332	2/3/78	336	376	75	131	157	66
333	2/4/78	-	-	-	-	-	-
334	2/5/78	-	-	-	-	-	-
335	2/6/78	460	307	87	91	136	74
336	2/7/78	364	187	85	-	179	78
337	2/8/78	380	371	124	-	277	92
338	2/9/78	696	405	145	-	221	132
339	2/10/78	340	301	101	-	152	89
340	2/11/78	-	-	-	-	-	-
341	2/12/78	-	-	-	-	-	-
342	2/13/78	380	299	85	109	176	74
343	2/14/78	464	456	108	-	213	90
344	2/15/78	432	536	99	-	237	87
345	2/16/78	408	592	115	-	445	103
346	2/17/78	400	360	-	-	208	100
347	2/18/78	-	-	-	-	-	-
348	2/19/78	-	-	-	-	-	-
349	2/20/78	-	-	-	-	-	-
350	2/21/78	508	475	157	277	283	120
351	2/22/78	772	499	235	-	272	177
352	2/23/78	476	517	136	-	219	114
353	2/24/78	440	424	152	-	259	113

continued.

TABLE A-1. (continued)

		TSS (mg/l)			
		RBC			RBC
Day	Date	Raw	In	Out	Sludge
1	3/9/77	136	161	37	-
2	3/10/77	294	156	33	-
3	3/11/77	145	144	44	-
4	3/12/77	143	201	45	-
5	3/13/77	139	183	61	-
6	3/14/77	188	161	26	-
7	3/15/77	234	131	31	-
8	3/16/77	155	128	23	19,060
9	3/17/77	141	100	20	20,700
10	3/18/77	160	111	19	22,020
11	3/19/77	125	112	37	27,780
12	3/20/77	-	-	-	22,260
13	3/21/77	136	132	27	27,650
14	3/22/77	154	125	21	22,000
15	3/23/77	83	91	16	25,240
16	3/24/77	63	51	11	22,000
17	3/25/77	155	-	29	25,200
18	3/26/77	158	-	28	22,500
19	3/27/77	-	87	19	14,100
20	3/28/77	-	194	83	16,200
21	3/29/77	322	175	27	17,500
22	3/30/77	282	132	11	16,000
23	3/31/77	168	159	36	13,800
24	4/1/77	99	116	17	23,200
25	4/2/77	119	116	15	17,200
26	4/3/77	101	114	11	18,800
27	4/4/77	150	117	8	16,300
28	4/5/77	188	132	22	19,00
29	4/6/77	48	-	36	20,600
30	4/7/77	136	100	15	20,400
31	4/8/77	-	-	-	-
32	4/9/77	-	-	-	-
33	4/10/77	-	-	-	-
34	4/11/77	206	132	25	22,600
35	4/12/77	178	146	29	25,200
36	4/13/77	162	108	20	33,000
37	4/14/77	161	100	14	30,600
38	4/15/77	150	110	23	25,400
39	4/16/77	-	91	17	16,300
40	4/17/77	-	89	21	13,400

continued.

TABLE A-1. (continued)

Day	Date	TSS (mg/l) RBC Raw	TSS (mg/l) RBC In	TSS (mg/l) Out	TSS (mg/l) RBC Sludge
41	4/18/77	178	127	17	18,400
42	4/19/77	212	109	33	10,000
43	4/20/77	192	125	22	21,800
44	4/21/77	308	131	25	19,700
45	4/22/77	137	96	22	14,200
46	4/23/77	119	104	20	27,100
47	4/24/77	149	168	26	13,000
48	4/25/77	181	151	21	36,400
49	4/26/77	198	116	26	22,800
50	4/27/77	110	108	24	-
51	4/28/77	160	81	22	-
52	4/29/77	148	108	25	-
53	4/30/77	234	170	9	-
54	5/1/77	140	136	19	-
55	5/2/77	148	134	22	-
56	5/3/77	195	120	15	29,700
57	5/4/77	220	113	9	33,700
58	5/5/77	238	106	26	28,200
59	5/6/77	172	121	40	38,900
60	5/7/77	-	-	-	19,400
61	5/8/77	-	-	-	14,600
62	5/9/77	153	111	13	24,400
63	5/10/77	168	168	38	24,800
64	5/11/77	193	143	26	16,800
65	5/12/77	132	114	21	18,200
66	5/13/77	175	147	28	11,600
67	5/14/77	115	118	25	23,200
68	5/15/77	173	103	13	24,600
69	5/16/77	234	125	20	25,600
70	5/17/77	104	134	26	28,900
71	5/18/77	206	145	54	33,800
72	5/19/77	190	115	49	16,800
73	5/20/77	-	-	-	35,900
74	5/21/77	132	97	44	29,800
75	5/22/77	244	137	45	21,300
76	5/23/77	219	141	61	22,700
77	5/24/77	248	149	77	26,600
78	5/25/77	164	123	57	15,800
79	5/26/77	173	122	45	29,000
80	5/27/77	143	141	46	26,100

continued.

TABLE A-1. (continued)

		TSS (mg/l)			
		RBC			RBC
Day	Date	Raw	In	Out	Sludge
81	5/28/77	155	109	53	36,400
82	5/29/77	103	96	38	11,100
83	5/30/77	186	92	26	17,900
84	5/31/77	-	-	-	24,900
85	6/1/77	186	143	78	11,900
86	6/2/77	184	152	59	11,000
87	6/3/77	164	113	72	17,600
88	6/4/77	169	126	77	31,300
89	6/5/77	179	117	58	18,900
90	6/6/77	130	74	59	34,400
91	6/7/77	-	-	-	26,600
92	6/8/77	-	-	-	25,500
93	6/9/77	205	175	82	26,000
94	6/10/77	67	79	38	30,300
95	6/11/77	-	-	-	44,100
96	6/12/77	135	105	56	39,800
97	6/13/77	108	106	35	41,100
98	6/14/77	252	146	78	-
99	6/15/77	344	125	92	18,500
100	6/16/77	252	105	46	32,670
101	6/17/77	147	107	30	23,700
102	6/18/77	140	109	51	22,360
103	6/19/77	-	-	-	21,330
104	6/20/77	240	154	53	16,580
105	6/21/77	299	189	105	16,630
106	6/22/77	128	136	65	23,080
107	6/23/77	149	137	38	26,270
108	6/24/77	122	138	39	13,200
109	6/25/77	136	136	48	27,090
110	6/26/77	222	163	60	21,730
111	6/27/77	135	122	39	17,730
112	6/28/77	182	147	66	-
113	6/29/77	175	147	74	23,270
114	6/30/77	-	-	-	26,900
115	7/1/77	113	95	43	13,900
116	7/2/77	-	-	-	-
117	7/3/77	-	-	-	-
118	7/4/77	-	-	-	-
119	7/5/77	-	-	-	21,170
120	7/6/77	289	181	58	26,000

continued.

TABLE A-1. (continued)

		TSS (mg/l)			
		RBC			
Day	Date	Raw	In	Out	RBC Sludge
121	7/7/77	302	180	66	22,360
122	7/8/77	332	128	58	17,830
123	7/9/77	214	130	51	3,290
124	7/10/77	216	95	23	10,690
125	7/11/77	207	99	15	15,410
126	7/12/77	258	83	52	9,000
127	7/13/77	252	108	21	13,080
128	7/14/77	170	107	24	10,460
129	7/15/77	157	106	40	2,620
130	7/16/77	136	105	44	22,400
131	7/17/77	170	95	39	16,000
132	7/18/77	203	98	15	17,640
133	7/19/77	143	145	38	23,640
134	7/20/77	134	139	37	27,730
135	7/21/77	156	138	40	20,000
136	7/22/77	170	-	31	30,080
137	7/23/77	20	-	-	6,720
138	7/24/77	134	108	31	6,520
139	7/25/77	155	118	19	11,690
140	7/26/77	229	142	55	11,140
141	7/27/77	151	108	71	7,650
142	7/28/77	127	163	27	12,120
143	7/29/77	-	-	-	-
144	7/30/77	152	202	31	27,200
145	7/31/77	149	-	10	29,200
146	8/1/77	171	129	15.2	19,200
147	8/2/77	304	133	14.9	22,960
148	8/3/77	178	197	35.2	43,040
149	8/4/77	167	110	9.6	22,000
150	8/5/77	197	105	5.3	22,800
151	8/6/77	122	90	6	23,090
152	8/7/77	102	56	19	36,080
153	8/8/77	218	83	9	24,560
154	8/9/77	172	75	43	29,610
155	8/10/77	278	99	26	31,100
156	8/11/77	214	100	27	31,200
157	8/12/77	280	79	18	38,800
158	8/13/77	182	99	34	22,500
159	8/14/77	135	52	17	12,000
160	8/15/77	130	-	33	30,300

continued.

TABLE A-1. (continued)

		TSS (mg/l)			
		RBC			RBC
Day	Date	Raw	In	Out	Sludge
161	8/16/77	169	212	80	21,000
162	8/17/77	180	179	33	35,800
163	8/18/77	174	157	34	23,100
164	8/19/77	148	133	42	17,400
165	8/20/77	152	104	23	26,400
166	8/21/77	125	104	22	27,200
167	8/22/77	205	136	22	30,100
168	8/23/77	136	112	21	28,800
169	8/24/77	168	-	81	25,600
170	8/25/77	149	167	30	31,100
171	8/26/77	99	112	32	24,200
172	8/27/77	89	108	19	25,000
173	8/28/77	127	95	7	25,700
174	8/29/77	234	107	13	25,200
175	8/30/77	208	156	30	23,700
176	8/31/77	373	141	26	31,400
177	9/1/77	227	173	145	23,000
178	9/2/77	139	133	45	16,700
179	9/3/77	-	87	14	25,900
180	9/4/77	104	39	9	21,800
181	9/4/77	256	90	12	18,400
183	9/7/77	126	96	14	22,500
184	9/8/77	113	77	34	25,200
185	9/9/77	307	224	30	29,300
186	9/10/77	155	174	52	27,300
187	9/11/77	106	106	29	26,400
188	9/12/77	117	100	27	24,500
189	9/13/77	143	130	14	22,100
190	9/14/77	181	125	27	24,400
191	9/15/77	104	149	39	40,400
192	9/16/77	111	147	30	25,900
193	9/17/77	141	108	26	20,800
194	9/18/77	105	74	93	27,500
195	9/19/77	59	95	16	26,400
196	9/20/77	156	123	14	38,300
197	9/21/77	159	87	28	21,900
198	9/22/77	-	-	-	-
199	9/23/77	138	110	39	26,360
200	9/24/77	109	-	14	25,140

continued.

TABLE A-1. (continued)

		TSS (mg/l)			
		RBC			RBC
Day	Date	Raw	In	Out	Sludge
201	9/25/77	-	-	-	-
202	9/26/77	-	-	-	-
203	9/27/77	-	-	-	-
204	9/28/77	-	-	-	-
205	9/29/77	-	-	-	-
206	9/30/77	-	-	-	-
207	10/1/77	-	-	-	-
208	10/2/77	-	-	-	-
209	10/3/77	-	-	-	-
210	10/4/77	135	154	34	22,940
211	10/5/77	105	130	8	22,060
212	10/6/77	129	117	20	22,100
213	10/7/77	90	103	15	22,100
214	10/8/77	-	-	-	-
215	10/9/77	-	-	-	-
216	10/10/77	75	99	12	26,500
217	10/11/77	106	101	18	31,320
218	10/12/77	127	95	314	30,480
219	10/13/77	121	145	70	29,540
220	10/14/77	86	119	19	33,880
221	10/15/77	163	128	13	23,816
222	10/16/77	68	102	3	19,180
223	10/17/77	136	114	8	23,340
224	10/18/77	118	113	50	21,346
225	10/19/77	-	104	-	17,388
226	10/20/77	99	102	42	13,448
227	10/21/77	60	49	40	13,872
228	10/22/77	-	46	9	12,644
229	10/23/77	31	69	17	12,688
230	10/24/77	130	58	17	13,120
231	10/25/77	140	147	29	13,400
232	10/26/77	172	138	19	13,620
233	10/27/77	50	112	26	26,300
234	10/28/77	163	197	120	20,600
235	10/29/77	180	110	45	30,900
236	10/30/77	194	156	21	26,700
237	10/31/77	238	104	26	31,500
238	11/1/77	208	172	34	28,800
239	11/2/77	346	154	45	24,100
240	11/3/77	292	152	40	26,900

continued.

TABLE A-1. (continued)

		TSS (mg/l)			
		RBC			RBC
Day	Date	Raw	In	Out	Sludge
241	11/4/77	164	150	42	30,280
242	11/5/77	117	146	33	23,410
243	11/6/77	147	175	57	23,300
244	11/7/77	-	138	56	28,050
245	11/8/77	-	-	-	-
246	11/9/77	-	-	-	-
247	11/10/77	77	64	22	25,710
248	11/11/77	142	99	45	28,900
249	11/12/77	104	83	33	24,780
250	11/13/77	60	83	25	21,200
251	11/14/77	126	100	72	18,800
252	11/15/77	152	103	70	22,000
253	11/16/77	199	130	68	19,210
254	11/17/77	125	102	51	13,270
255	11/18/77	109	111	47	27,140
256	11/19/77	86	97	43	27,030
257	11/20/77	72	109	30	16,650
258	11/21/77	178	110	31	26,380
259	11/22/77	304	105	45	19,300
260	11/23/77	211	112	35	21,630
261	11/24/77	-	-	-	-
262	11/25/77	-	-	-	-
263	11/26/77	-	-	-	-
264	11/27/77	-	-	-	-
265	11/28/77	-	-	-	-
266	11/29/77	-	-	-	-
267	11/30/77	-	-	-	-
268	12/1/77	-	-	-	-
269	12/2/77	-	-	-	-
270	12/3/77	-	-	-	-
271	12/4/77	-	-	-	-
272	12/5/77	-	-	-	-
273	12/6/77	136	170	66	28,480
274	12/7/77	121	126	32	29,140
275	12/8/77	119	118	34	25,270
276	12/9/77	100	86	30	22,910
277	12/10/77	123	-	-	19,190
278	12/11/77	-	-	-	19,450
279	12/12/77	153	86	22	20,150
280	12/13/77	168	197	-	15,220

continued.

TABLE A-1. (continued)

		TSS (mg/l)			
		RBC			RBC
Day	Date	Raw	In	Out	Sludge
281	12/14/77	163	142	25	12,540
282	12/15/77	162	152	32	10,540
283	12/16/77	88	98	10	13,960
284	12/17/77	83	110	10	27,240
285	12/18/77	78	140	17	25,850
286	12/19/77	108	110	16	20,180
287	12/20/77	98	125	11	21,540
288	12/21/77	121	136	10	23,450
289	12/22/77	-	-	-	-
290	12/23/77	-	-	-	-
291	12/24/77	-	-	-	-
292	12/25/77	-	-	-	-
293	12/26/77	-	-	-	-
294	12/27/77	-	-	-	-
295	12/28/77	-	-	-	-
296	12/29/77	-	-	-	-
297	12/30/77	-	-	-	-
298	12/31/77	-	-	-	-
299	1/1/78	-	-	-	-
300	1/2/78	-	-	-	-
301	1/3/78	129	133	18	11,970
302	1/4/78	188	125	-	5,790
303	1/5/78	176	162	36	28,520
304	1/6/78	123	102	59	26,610
305	1/7/78	183	126	28	20,440
306	1/8/78	127	134	34	16,520
307	1/9/78	152	153	25	17,940
308	1/10/78	168	86	14	16,930
309	1/11/78	134	104	-	17,030
310	1/12/78	236	106	32	18,220
311	1/13/78	92	102	33	24,280
312	1/14/78	36	43	22	20,480
313	1/15/78	161	144	28	21,720
314	1/16/78	91	99	20	19,280
315	1/17/78	200	93	13	18,600
316	1/18/78	345	153	16	19,420
317	1/19/78	128	83	7	18,820
318	1/20/78	180	120	17	22,620
319	1/21/78	189	129	28	22,000
320	1/22/78	164	79	2	20,850

continued.

TABLE A-1. (continued)

Day	Date	TSS (mg/l)			
		RBC			
		Raw	In	Out	RBC Sludge
321	1/23/78	146	127	36	24,600
322	1/24/78	188	174	13	25,880
323	1/25/78	194	143	15	24,110
324	1/26/78	241	137	9	22,510
325	1/27/78	89	70	4	17,340
326	1/28/78	284	106	14	20,260
327	1/29/78	147	90	13	22,220
328	1/30/78	178	81	14	27,410
329	1/31/78	257	171	10	22,710
330	2/1/78	393	195	14	20,190
331	2/2/78	207	243	15	26,870
332	2/3/78	233	157	23	24,020
333	2/4/78	207	110	26	18,040
334	2/5/78	192	118	29	15,640
335	2/6/78	210	116	19	19,340
336	2/7/78	220	147	29	25,290
337	2/8/78	225	116	40	21,630
338	2/9/78	310	129	24	18,290
339	2/10/78	231	123	30	18,170
340	2/11/78	57	134	39	27,170
341	2/12/78	251	131	35	21,980
342	2/13/78	245	159	28	24,270
343	2/14/78	311	230	22	18,320
344	2/15/78	217	217	20	20,670
345	2/16/78	260	240	24	12,910
346	2/17/78	209	155	20	23,980
347	2/18/78	298	107	32	25,780
348	2/19/78	259	136	22	25,730
349	2/20/78	-	-	-	18,410
350	2/21/78	183	162	45	31,420
351	2/22/78	349	164	54	27,100
352	2/23/78	307	211	35	-
353	2/24/78	208	128	13	-

TABLE A-2. EDGEWATER NITROGEN DATA SUMMARY

		NO_3-N					
	Raw	RBC		Stage			
Date	inf.	Inf.	Eff.	1	2	3	4
3/16/77	0.1	0.9	0.6	0.1			
3/28/77		0.1	3.3				
4/1/77	0.1	0.1	1.8				
4/4/77	0.1	2.6	0.1				
4/7/77	0.9	2.2	4.3				
4/11/77	0.2	0.5	0.9				
4/13/77	0.1	0.1	0.4	0.1	0.1	0.1	0.1
4/15/77	0.5	0.7	0.6	0.2	0.1	0.1	0.1
4/18/77	0.1	0.1	0.5				
4/20/77	0.1	0.2	0.5	0.1	0.1	0.1	0.1
4/22/77	0.2	0.1	0.5				
4/27/77	0.1	0.1	0.1				
4/29/77	0.4	0.7	0.1				
5/2/77	0.4	0.2	1.2				
5/4/77	1.6	0.1	0.1	0.1	0.1	-	2.1
5/6/77		0.1	0.1				
5/9/77	0.1	3.1	2.1				
5/11/77	1.8	0.9	0.1	0.1	0.1	2.9	2.2
5/13/77	9.8	0.1	0.1				
6/1/77	0.3	0.2	0.1	0.1	-	0.1	0.1
6/6/77	0.1	0.1	0.1				
6/9/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
6/10/77	0.1	0.1	0.1				
6/13/77		0.1	0.1				
6/16/77		0.1	0.1	0.1	0.1	0.1	0.1
6/17/77		0.1	0.1				
6/20/77		0.1	0.1				
6/22/77		0.1	0.1	0.1	0.1	0.1	0.1
6/27/77		0.1	0.1				
6/29/77		0.1	0.1				
7/7/77		0.1	0.1	0.1	0.1	0.1	0.1
7/20/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
7/22/77		0.1	0.1	0.1	0.1	0.1	0.1
7/25/77		0.1	0.1	-	-	-	-
7/27/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
8/1/77		0.2	0.2				
8/4/77		0.1	0.1	0.1	0.1	0.1	0.1
8/5/77		-	0.1	0.1	0.1	0.1	0.1

continued.

TABLE A-2. (continued)

Date	Raw inf.	NO_3-N					
		RBC		Stage			
		Inf.	Eff.	1	2	3	4
8/8/77		-	0.3				
8/10/77		-	0.1	0.1	0.1	0.1	0.1
8/12/77		-	-	0.1	0.1	0.1	0.1
8/17/77		-	0.6	0.1	0.1	0.1	0.1
8/19/77		-	0.4	0.1	0.1	0.1	0.1
8/24/77		-	0.6	0.1	0.1	0.1	0.8
8/26/77		-	0.5	0.1	0.1	0.1	0.3
8/29/77		-	1.2				
8/31/77		-	1.5	0.1	0.1	0.1	0.5
9/2/77							
9/14/77		0.1	0.2				
10/17/77		-	0.5				
10/25/77		-	-				
10/31/77		0.1	0.1				
12/21/77							
1/27/78		1.8	2.1	1.6	1.6	2.1	2.5
2/3/78		0.7	0.8	0.5	0.1	0.1	0.9
2/10/78		0.9	0.5	0.4	0.1	0.3	0.6
2/17/78		0.8	0.3	0.1	0.1	0.2	0.3
2/24/78		0.9	0.1	0.3	0.1	0.4	0.1

continued.

TABLE A-2. (continued)

		TKN Total					
	Raw	RBC		Stage			
Date	inf.	inf.	eff.	1	2	3	4
3/16/77	24.4	22.5	14.2				
3/28/77		20.2	11.2				
4/1/77	19.5	18.8	11.8				
4/4/77	20.1	20.2	9.8				
4/7/77	47.4	44.2	28.5				
4/11/77	34.5	31.9	12.2				
4/13/77	19.4	11.8	11.8	29.9	29.1	27.8	22.3
4/15/77	34.0	29.9	16.4	23.8	22.8	22.3	28.3
4/18/77	40.8	35.0	22.2				
4/20/77	21.1	22.3	16.0	19.1	19.4	17.4	21.7
4/22/77	23.1	19.4	14.5				
4/27/77	25.5	23.1	14.9				
4/29/77	24.8	23.0	15.1				
5/2/77	27.7	26.1	16.8				
5/4/77	25.8	26.4	17.3	26.9	36.1	-	39.6
5/6/77		24.1	14.3				
5/9/77	20.5	28.0	14.2				
5/11/77	37.7	34.6	17.6	15.9	24.7	16.7	24.1
5/13/77	34.0	19.2	15.7				
6/1/77	28.5	24.4	33.6	32.4	-	31.7	24.4
6/6/77	26.6	29.9	21.0				
6/9/77	26.3	29.3	26.8	25.0	35.7	25.7	26.7
6/10/77	29.7	11.6	14.0				
6/13/77		25.2	18.7				
6/16/77		16.1	18.9				
6/17/77		21.3	19.6				
6/20/77		19.4	15.9				
6/22/77							
6/27/77		24.6	17.5				
6/29/77		22.4	16.6				
7/1/77		24.8	16.3				
7/20/77	20.3	24.4	18.2	22.6	28.4	18.8	18.2
7/22/77		24.1	17.7	22.5	40.0	24.5	23.0

continued.

TABLE A-2. (continued)

		TKN Total					
	Raw	RBC		Stage			
Date	inf.	inf.	eff.	1	2	3	4
7/25/77		29.9	28.2	-	-	-	-
7/27/77	14.0	23.3	17.0	22.0	32.2	20.3	13.6
8/1/77	24.9	22.8	17.2	-	-	-	-
8/4/77		26.9	26.1	24.4	26.5	21.8	19.8
8/5/77	26.9	22.7	17.1	-	-	-	-
8/8/77	26.4	23.3	18.1				
8/10/77	25.4	22.4	14.9	27.5	51.9	27.0	18.3
8/12/77	26.2	23.0	15.9	-	-	-	-
8/17/77	25.9	26.2	15.9	25.6	21.5	21.4	18.8
8/19/77		23.1	17.2				
8/24/77		23.4	13.4	27.0	25.9	23.9	23.2
8/26/77	22.1	23.6	15.0	22.2	27.5	29.3	21.0
8/29/77	21.8	25.2	15.4				
8/31/77	25.9	23.3	16.3	23.6	26.1	20.7	18.3
9/2/77		22.6	16.3				
9/14/77	30.1	30.0	21.7	29.4	24.5	26.2	26.1
10/17/77	23.9	23.9	15.5				
10/25/77	21.6	22.1	16.1				
10/31/77		-	-				
12/21/77	16.1	13.3	11.4				
1/27/78	9.9	8.9	3.7	7.4	10.3	7.2	6.3
2/3/78	29.1	24.1	15.4	20.3	31.0	26.6	17.1
2/10/78		25.4	16.8	27.5	25.4	17.8	19.5
2/17/78	29.8	27.4	17.3	31.2	30.3	30.9	28.0
2/24/78		25.1	15.7	20.8	22.1	17.4	14.9

continued.

TABLE A-2. (continued)

		TKN Filtered					
	Raw	RBC		Stage			
Date	inf.	inf.	eff.	1	2	3	4
3/16/77							
3/28/77	14.0	9.9					
4/1/77	18.7	17.9	12.0				
4/4/77	16.8	14.4	9.0				
4/7/77	19.4	15.7	27.2				
4/11/77	14.2	20.7	11.8				
4/13/77	17.0	15.7	11.0	19.8	21.3	20.6	17.7
4/15/77	25.8	24.7	15.6	23.8	21.0	18.3	12.1
4/18/77	30.3	32.1	20.7				
4/20/77	21.1	22.8	15.6	22.3	15.9	23.4	15.3
4/22/77	21.5	21.4	14.7				
4/27/77	23.4	22.8	14.9				
4/29/77	24.3	21.9	14.8				
5/2/77		23.7	16.1				
5/4/77	24.1	26.0	16.9	22.0	26.0	-	16.6
5/6/77		23.0	16.7				
5/9/77	22.3	21.5	14.2				
5/11/77	30.7	24.7	17.4	23.5	21.5	22.2	23.6
5/13/77	30.6	30.0	19.3				
6/1/77	21.1	29.3	20.1	20.7	-	22.7	27.3
6/6/77	21.9	25.0	20.4				
6/9/77	20.0	22.2	20.3	19.7	23.6	23.4	19.5
6/10/77	8.7	6.5	5.9				
6/13/77	19.4	18.1					
6/16/77	14.6	16.5					
6/17/77	19.8	17.0					
6/20/77	17.8	15.7					
6/22/77	21.8	14.7					
6/27/77	21.4	15.7					
6/29/77	17.6	13.0					
7/1/77	19.8	14.5					
7/20/77	-	-	-	-	-	-	-
7/22/77	-	-	-	-	-	-	-

continued.

TABLE A-2. (continued)

Date	Raw inf.	TKN Filtered RBC inf.	RBC eff.	Stage 1	2	3	4
7/25/77		20.6	15.9	-	-	-	-
7/27/77		18.5	13.7	-	-	-	-
8/1/77		32.0	16.6	-	-	-	-
8/4/77		-	15.6	16.2	19.2	19.8	16.2
8/5/77		-	15.6	-	-	-	-
8/8/77		-	-				
8/10/77	19.7	16.0	12.4	19.9	16.9	14.0	9.7
8/12/77		-	15.0	-	-	-	-
8/17/77	20.6	19.8	14.6	18.4	18.2	14.9	14.0
8/19/77		18.8	13.8	17.6	17.3	16.8	15.8
8/24/77		18.1	11.6	21.8	19.3	18.5	16.9
8/26/77	19.7	20.2	13.4	18.6	18.6	16.8	14.6
8/29/77		21.0	14.1				
8/31/77	18.2	18.6	12.5	17.8	15.4	14.6	9.1
9/2/77		18.1	14.2				
9/14/77	23.2	20.9	19.5	22.3	21.2	26.2	26.6
10/17/77		-	14.5				
10/25/77		-	-				
10/31/77		-	-				
12/21/77		12.9	10.3				
1/27/78		7.0	2.3	6.0	6.6	5.9	3.3
2/3/78		11.7	13.9	17.8	17.9	15.3	15.3
2/10/78	28.0	24.4	16.4	22.2	18.2	16.0	18.6
2/17/78		22.2	15.1	24.0	19.5	22.1	16.2
2/24/78	25.0	17.4	14.9	15.9	15.1	11.5	12.9

continued.

TABLE A-2. (continued)

		NH_3-N					
	Raw	RBC		Stage			
Date	inf.	inf.	eff.	1	2	3	4
3/16/77	9.4	5.9	9.0				
3/28/77		12.3	7.6				
4/1/77	12.9	12.7	9.5				
4/4/77	13.0	7.0	12.3				
4/7/77	8.9	4.2	3.6				
4/11/77	16.2	15.3	10.7				
4/13/77	10.3	9.7	11.3	13.9	14.4	11.4	10.2
4/15/77	11.6	9.9	11.2	14.2	14.1	12.9	12.6
4/18/77	15.2	14.9	14.1				
4/20/77	13.4	12.5	12.9	15.6	15.8	14.2	13.2
4/22/77	13.2	12.1	13.2				
4/27/77	8.1	11.3	12.7				
4/29/77	12.3	12.8	13.1				
5/2/77	16.7	17.9	14.2				
5/4/77	14.1	12.4	13.3	17.3	20.7	-	13.6
5/6/77		16.1	12.1				
5/9/77	11.8	10.1	11.8				
5/11/77	15.6	16.3	11.4	12.6	14.3	11.5	12.1
5/13/77	15.0	21.8	15.7				
6/1/77	16.5	15.8	16.1	16.9	-	16.5	18.5
6/6/77	20.7	22.1	16.7				
6/9/77	18.8	19.0	16.5	18.9	20.2	18.3	18.7
6/10/77	5.3	6.1	5.0				
6/13/77		17.8	15.6				
6/16/77		14.0	16.0	16.0	16.5	14.2	13.8
6/17/77		16.5	14.3				
6/20/77		16.8	15.6				
6/22/77		14.3	14.0	16.8	20.1	14.5	15.9
6/27/77		17.9	14.5				
6/29/77		14.6	12.8				
7/1/77		15.9	14.3	16.3	16.5	15.8	14.7
7/20/77	12.8	14.2	11.5	13.1	13.9	12.3	11.6
7/22/77		15.0	12.0	14.9	15.7	13.9	13.8

continued.

TABLE A-2. (continued)

		NH_3-N					
		RBC		Stage			
Date	Raw inf.	inf.	eff.	1	2	3	4
7/25/77		15.9	13.4	-	-	-	-
7/27/77	13.4	14.6	11.9	13.4	14.2	12.6	12.6
8/1/77	16.7	17.8	13.9	-	-	-	-
8/4/77		15.3	12.1	14.9	14.0	12.2	10.4
8/5/77	14.5	14.4	12.7	15.5	14.2	13.9	12.8
8/8/77	15.9	15.9	13.1				
8/10/77	14.0	13.3	9.2	13.5	13.9	10.8	9.4
8/12/77	14.1	13.2	10.7	14.7	14.6	10.3	11.4
8/17/77	14.3	14.6	11.3	14.7	13.6	11.1	10.8
8/19/77		14.5	12.1	14.7	14.3	13.3	12.3
8/24/77		12.0	9.4	15.4	17.0	16.6	15.2
8/26/77	14.0	13.3	10.7	14.6	14.2	13.3	12.3
8/29/77	16.3	16.4	11.6				
8/31/77	13.4	12.6	9.8	13.7	13.0	12.0	9.9
9/2/77		14.1	12.3				
9/14/77	17.2	18.7	16.1	17.3	15.6	13.0	13.3
10/17/77	13.6	13.3	12.0				
10/25/77	15.6	15.1	13.2				
10/31/77		26.8	16.5				
12/21/77	6.5	5.6	6.6				
1/27/78	3.3	2.2	1.7	2.9	3.0	3.2	1.3
2/3/78	11.8	8.0	9.6	13.3	12.6	11.3	9.7
2/10/78	11.5	8.7	12.4	13.0	12.8	12.0	14.4
2/17/78	15.7	11.9	12.5	15.6	15.0	19.0	12.3
2/24/78	11.7	9.9	11.7	12.5	13.2	12.0	11.8

continued.

TABLE A-2. (continued)

		NO_2-N					
		RBC		Stage			
Date	Raw inf.	inf.	eff.	1	2	3	4
3/16/77	0.1	0.1	0.1				
3/28/77		0.1	0.1				
4/1/77	0.11	0.1	0.1				
4/4/77	0.1	0.2	0.1				
4/7/77	0.1	0.1	0.1				
4/11/77	0.1	0.1	0.2				
4/13/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
4/15/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
4/18/77	0.1	0.1	0.1				
4/20/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
4/22/77	0.1	0.1	0.1				
4/27/77	0.1	0.1	0.1				
4/29/77	0.1	0.1	0.1				
5/2/77	0.1	0.1	0.1				
5/4/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5/6/77		0.1	0.1				
5/9/77	0.1	0.1	0.1				
5/11/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5/13/77	0.1	0.1	0.1				
6/1/77	0.1	0.1	0.1	0.1	-	0.1	0.1
6/6/77	0.1	0.1	0.1				
6/9/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
6/10/77	0.1	0.1	0.1				
6/13/77		0.1	0.1				
6/16/77		0.1	0.1	0.1	0.1	0.1	0.1
6/17/77		0.1	0.1				
6/20/77		0.1	0.1				
6/22/77		0.1	0.1	0.1	0.1	0.1	0.1
6/27/77		0.1	0.1				
6/29/77		0.1	0.1				
7/1/77		0.1	0.1	0.1	0.1	0.1	0.1
7/20/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
7/22/77		0.1	0.1	0.1	0.1	0.1	0.1

continued.

TABLE A-2. (continued)

		NO_2-N					
	Raw	RBC		Stage			
Date	inf.	inf.	eff.	1	2	3	4
7/25/77		0.1	0.1	-	-	-	-
7/27/77	0.1	0.1	0.1	0.1	0.1	0.1	0.1
8/1/77		0.1	0.3	-	-	-	-
8/4/77		0.1	0.3	0.1	0.1	0.1	0.4
8/5/77		-	0.3	0.1	0.1	0.1	0.4
8/8/77		-	0.2				
8/10/77		-	0.1	0.1	0.1	0.1	0.1
8/12/77		-	-	0.1	0.1	0.1	0.1
8/17/77		-	0.1	0.1	0.1	0.1	0.1
8/19/77		-	0.1	0.1	0.1	0.1	0.1
8/24/77		-	0.1	0.1	0.1	0.1	0.1
8/26/77		-	0.1	0.1	0.1	0.1	0.1
8/29/77		-	0.1				
8/31/77		-	0.1	0.1	0.1	0.1	0.1
9/2/77							
9/14/77		0.1	0.1				
10/17/77		-	0.2				
10/25/77		-	-				
10/31/77		0.1	1.9				
12/21/77							
1/27/78		0.1	0.2	0.1	0.1	0.2	0.2
2/3/78		0.1	0.1	0.1	0.1	0.1	0.1
2/10/78		0.1	0.1	0.1	0.1	0.1	0.1
2/17/78		0.1	0.1	0.1	0.1	0.1	0.1
2/24/78		0.1	0.1	0.1	0.1	0.1	0.1

continued.

TABLE A-3. EDGEWATER RBC DATA - SULPHUR

		$S^=$ (mg/l)					
	Raw	RBC		Stage			
Date	inf.	inf.	eff.	1	2	3	4
3/16/77		0.1	0.1				
3/28/77		0.1	0.1				
4/7/77		0.1	0.1				
4/13/77		0.1	0.1				
4/20/77		0.1	0.1				
4/27/77		0.1	0.1				
5/4/77	0.1	0.1	0.1	0.1	0.3	-	1.3
5/6/77		0.1	0.1				
5/9/77	0.1	0.1	0.1				
5/11/77		-	-	-	0.8	1.1	0.8
5/13/77		-	-				
6/1/77	0.1	0.1	0.1	0.1	-	0.1	4.0
6/6/77	0.1	0.1	0.1				
6/9/77	0.1	0.1	0.1	1.3	7.0	2.0	4.0
6/10/77	0.1	0.1	0.1				
6/16/77		0.1	0.1				
6/20/77		0.1	0.1	0.1	1.2	0.1	0.1
7/8/77		0.1	0.1	0.1	0.9	0.1	0.1
7/20/77		0.1	0.1	0.1	0.2	0.1	0.1
7/27/77		0.1	0.1	0.1	1.1	0.1	0.1
8/4/77		0.1	0.1	0.1	0.3	0.1	0.1
8/17/77		0.1	0.1	0.1	0.1	0.1	0.1
8/19/77		0.1	0.1	-	-	-	-
8/24/77		-	0.1	0.1	0.1	0.1	0.1
8/26/77		-	0.1	0.1	0.1	0.1	0.1
8/31/77		-	0.1	0.2	0.1	0.3	0.1
9/14/77		0.1	0.1	0.1	0.1	0.1	0.1
12/16/77		0.1	0.1	-	-	-	-
1/27/78	0.1	0.1	0.1	-	-	-	-
2/10/78	0.1	0.1	0.1	-	-	-	-
2/24/78	0.1	0.1	0.1	-	-	-	-

continued.

TABLE A-3. (continued)

Date	Raw inf.	SO$_4$ (mg/l)					
		RBC		Stage			
		inf.	eff.	1	2	3	4
3/16/77		67	70				
3/28/77		78.6	78.0				
4/7/77		76	77				
4/13/77		78	76				
4/20/77		75	73				
4/27/77		84	78				
5/4/77	88	80	80	75	63	-	55
5/6/77		108	78				
5/9/77	76	78	78				
5/11/77	96	92	65	78	80	78	76
5/13/77	100	96	80				
6/1/77		-	-	-	-	-	-
6/6/77	65	55	65				
6/9/77	90	95	90	130	85	100	75
6/10/77	65	70	70				
6/16/77		75	83				
6/20/77		150	110	130	92	116	128
7/8/77		46.4	60.8	36.4	11.2	36.7	46.4
7/20/77		74	90	76	30	70	70
7/27/77		95	89	66	49	68	89
8/4/77		42	65	48	29	66	57
8/17/77		69	75	73	75	89	50
8/19/77		84	86	-	-	-	-
8/24/77		-	144	190	164	154	144
8/26/77		77	87	94	78	79	83
8/31/77		166	120	145	135	170	130
9/14/77		65	84	51	58	64	86
12/16/77		55	60	-	-	-	-
1/27/78	54	54	52	-	-	-	-
2/10/78	75	85	75	-	-	-	-
2/24/78	73	93	93	-	-	-	-

TABLE A-4. EDGEWATER RBC DATA - GREASE & OIL (mg/1)

	Raw	RBC		Stage			
Date	**inf.**	**inf.**	**eff.**	**1**	**2**	**3**	**4**
4/20/77	24	20	113				
6/1/77	60.6	79.0	45.4				
6/16/77	59.4	64.7	19.3				
6/29/77	58	22	60				
7/27/77	23	36	3	9	36	18	15
8/4/77	50	17	1	12	26	2	6
8/17/77	27	40	39				
8/24/77	66	87	33	78	39	37	21
8/30/77	81	80	45				
9/14/77	20	27	1				
12/15/77	-	33	14				
1/9/78	31	23	15				
1/24/78	22	35	9				
2/9/78	96	45	11				
2/13/78	48	48	12				
2/21/78	48	42	14				

TABLE A-5. EDGEWATER RBC - PHOSPHATE DATA (mg/l)

Date	Ortho-phosphate (mg/l as P)			Total PO_4-P (mg/l)		
	Raw inf	RBC inf	RBC eff	Raw inf	RBC inf	RBC eff
8/30/77	5.50	4.76	5.87			
9/14/77	3.13	4.63	3.40			
2/9/78				4.50	4.25	2.60
2/13/78				4.75	4.63	2.88
2/21/78				5.38	5.50	4.25

TABLE A-6. ANALYSIS OF INTERSTAGE SAMPLES

					Chemical oxygen demand (COD) (mg/l)					
					RBC influent		Stages (S)			
Date	Day	Eff. temp. (C)	cu m day	Flow (mgd)	T	S	1	2	3	4
Low Loading Period: March 9-April 6, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)										
3/14/77	6	12.5	1343	(0.355)	205	134	74	61	94	54
3/16/77	8	13.0	1620	(0.428)	155	98	78	34	63	60
Average		12.8	1484	(0.392)	180	116	76	47.5	78.5	57
		0.4	197	(0.52)	35	25	3	19	22	4
Moderate Loading Period: April 11-May 13, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)										
4/13/77	36	16.0	1583	(0.418)	302	218	96	73	85	74
4/14/77	37	16.0	1540	(0.407)	238	180	117	105	72	73
4/15/77	38	15.0	1484	(0.392)	254	180	133	90	78	60
4/20/77	43	18.0	1495	(0.395)	286	208	133	109	101	88
5/4/77	57	18.0	1540	(0.407)	286	196	148	115	-	91
5/5/77	58	17.0	1469	(0.388)	330	258	210	142	126	106
5/11/77	64	18.0	1393	(0.368)	304	176	122	106	68	66
Average		16.9	1500	(0.396)	286	202	137	106	88	80
		1.2	60	(0.016)	31	29	36	21	22	16
High Loading Period: May 23-June 30, 1977; Baffles after Shafts 1, 2, 3 & 4 (6/16 & 6/17)										
6/1/77	85	23.0	2593	(0.685)	285	120	90	76	-	52
6/3/77	87	23.0	2593	(0.685)	-	-	-	-	-	-
6/9/77	93	-	2687	(0.710)	346	181	116	136	170	110
6/16/77	100	23.5	2687	(0.710)	325	184	124	130	128	97
6/17/77	101	24.0	2668	(0.705)	266	162	156	150	129	97
Average		23.4	2646	(0.699)	306	162	122	123	142	89
		0.5	49	(0.013)	37	29	27	32	24	25

continued.

TABLE A-6. (continued)

					Chemical oxygen demand (COD) (mg/1)					
					RBC influent		Stages (S)			
Date	Day	Eff. temp. (C)	cu m/day	Flow (mgd)	T	S	1	2	3	4
Baffles after Shafts 2, 3 & 4 (6" clearance)										
6/22/77	106	24.0	2744	(0.725)	389	288	236	188	173	179
6/23/77	107	24.0	2630	(0.695)	317	187	136	138	128	117
6/24/77	108	25.0	2725	(0.720)	275	155	100	120	101	89
6/29/77	113	25.0	2725	(0.720)	352	221	188	140	144	-
7/1/77	115	25.5	2930	(0.770)	243	172	152	152	117	89
Average		24.6	2751	(0.727)	295	205	162	148	133	119
		.67	110	(0.029)	42	53	52	25	28	42
Warm Temperature Period: July 18-September 23,1977; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)										
7/20/77	134	28.0	1862	(0.492)	285	170	112	126	120	89
7/21/77	135	28.0	1836	(0.485)	373	221	224	198	144	112
7/22/77	136	28.0	1900	(0.502)	357	245	188	194	164	116
7/27/77	141	27.0	1873	(0.495)	269	176	176	178	140	116
Average		28.0	1870	(0.494)	321	203	159	174	142	108
		.5	265	(0.007)	52	35	41	33	18	13
8/4/77	149	26.0	1533	(0.405)	268	175	168	136	127	81
8/5/77	150	27.0	1590	(0.420)	267	152	164	132	126	78
8/10/77	155	27.0	1457	(0.385)	288	195	188	142	103	88
8/11/77	156	27.0	1495	(0.395)	293	219	192	184	128	85
8/12/77	157	27.5	1457	(0.385)	344	224	252	216	157	108
8/17/77	162	26.0	1544	(0.408)	411	221	208	160	128	143
8/18/77	163	26.0	1495	(0.395)	352	240	212	152	137	-
8/19/77	164	26.0	1468	(0.388)	386	163	212	190	152	136

continued.

TABLE A-6. (continued)

					Chemical oxygen demand (COD) (mg/l)					
					RBC influent		Stages (S)			
Date	Day	Eff. temp. (C)	cu m day	Flow (mgd)	T	S	1	2	3	4
8/24/77	169	26.0	1435	(0.375)	152	180	222	110	113	100
8/25/77	170	24.0	1230	(0.325)	300	216	160	148	123	75
8/26/77	171	25.0	1438	(0.380)	319	264	198	162	151	111
8/31/77	176	26.0	1449	(0.383)	344	220	254	175	139	123
Average		26.2	1484	(0.392)	319	210	189	150	130	99
		1.0	49	(0.013)	45	32	19	22	15	22
Cold Temperature Period: December 1-February 24, 1978; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)										
1/5/78		12.0	1476	(0.390)	336	203	195	188	117	80
1/20/78	316	-	1563	(0.413)	109	59	52	38	32	28
1/25/78	323	-	1324	(0.350)	343	209	167	125	93	87
2/3/78	332	110	1476	(0.390)	376	157	120	98	81	72
2/10/78	337	11.0	1797	(0.475)	301	152	164	152	103	72
2/17/78	346	11.0	1457	(0.385)	360	208	188	126	99	96
2/24/78	353	12.0	1514	(0.400)	424	259	240	168	111	113
Average		11.4	1514	(0.400)	321	178	161	128	91	78
		.6	144	(0.038)	101	64	60	50	28	26

continued.

TABLE A-6. (continued)

					Biochemical oxygen demand 5-Day (BOD$_5$) (mg/l)					
					RBC influent		Stages (S)			
Date	Day	Eff. temp. (C)	cu m / day	Flow (mgd)	T	S	1	2	3	4
Low Loading Period: March 9-April 6, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)										
3/14/77	6	12.5	1343	(0.355)	79	26	19	16	24	13
3/16/77	8	13.0	1620	(0.428)	88	37	38	20	19	15
Average		12.8	1484	(0.392)	83.5	31.5	28.5	18	21.5	14
		0.4	197	(0.52)	6	8	13	3	4	1
Moderate Loading Period: April 11-May 13, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)										
4/13/77	36	16.0	1583	(0.418)	159	41	40	21	21	19
4/14/77	37	16.0	1540	(0.407)	159	35	22	26	16	17
4/15/77	38	15.0	1484	(0.392)	117	50	50	28	16	8
4/20/77	43	18.0	1495	(0.395)	191	210	70	48	39	27
5/4/77	57	18.0	1540	(0.407)	162	113	76	59	-	25
5/5/77	58	17.0	1469	(0.388)	221	180	108	53	48	47
5/11/77	64	18.0	1393	(0.368)	150	96	55	40	34	21
Average		16.9	1500	(0.396)	166	86	60	39	29	23
		1.2	60	(0.016)	33	56	28	15	13	12
High Loading Period: May 23-June 30, 1977; Baffles after Shafts 1, 2, 3 & 4 (6/16 & 6/17)										
6/1/77	85	23.0	2593	(0.685)	144	63	51	39	-	60
6/3/77	87	23.0	2593	(0.685)	144	80	70	49	52	52
6/9/77	93	-	2687	(0.710)	185	86	130	91	74	60
6/16/77	100	23.5	2687	(0.710)	128	78	-	77	55	37
6/17/77	101	24.0	2668	(0.705)	146	105	115	98	72	56
Average		23.4	2646	(0.699)	149	82	85	71	63	53
		0.5	49	(0.013)	21	15	29	26	11	10

continued.

TABLE A-6. (continued)

					Biochemical oxygen demand 5-Day (BOD_5) (mg/l)					
					RBC influent		Stages (S)			
Date	Day	Eff. temp. (C)	cu m / day	Flow (mgd)	T	S	1	2	3	4
Baffles after Shafts 2, 3 & 4 (6" clearance)										
6/22/77	106	24.0	2744	(0.725)	153	69	84	84	50	45
6/23/77	107	24.0	2630	(0.695)	128	57	57	64	45	25
6/24/77	108	25.0	2725	(0.720)	146	72	58	63	47	23
6/29/77	113	25.0	2725	(0.720)	152	84	79	94	70	-
7/1/77	115	25.5	2930	(0.770)	123	99	82	76	76	43
Average		24.6	2751	(0.727)	140	76	72	76	58	34
		.67	110	(0.029)	14	16	13	13	14	12
Warm Temperature Period: July 18-September 23,1977; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)										
7/20/77	134	28.0	1862	(0.492)	122	68	45	42	34	26
7/21/77	135	28.0	1836	(0.485)	156	114	73	83	63	36
7/22/77	136	28.0	1900	(0.502)	144	103	66	79	49	33
7/27/77	141	27.0	1873	(0.495)	105	73	41	67	41	25
Average		28.0	1870	(0.494)	132	90	56	68	47	30
		.5	265	(0.007)	23	22	16	18	12	5
8/4/77	149	26.0	1533	(0.405)	146	109	69	57	29	23
8/5/77	150	27.0	1590	(0.420)	138	94	59	41	27	17
8/10/77	155	27.0	1457	(0.385)	126	63	54	61	40	36
8/11/77	156	27.0	1495	(0.395)	122	116	81	50	38	41
8/12/77	157	27.5	1457	(0.385)	129	115	85	69	39	34
8/17/77	162	26.0	1544	(0.408)	112	74	67	49	36	21
8/18/77	163	26.0	1495	(0.395)	146	115	84	70	47	-
8/19/77	164	26.0	1468	(0.388)	141	90	72	43	42	32

continued.

TABLE A-6. (continued)

					Biochemical oxygen demand 5-Day (BOD_5) (mg/1)					
					RBC influent		Stages (S)			
Date	Day	Eff. temp. (C)	cu m day	Flow (mgd)	T	S	1	2	3	4
8/24/77	169	26.0	1435	(0.375)	120	72	39	28	17	8
8/25/77	170	24.0	1230	(0.325)	110	88	58	44	35	29
8/26/77	171	25.0	1438	(0.380)	170	145	91	66	42	24
8/31/77	176	26.0	1449	(0.383)	135	122	107	87	55	42
Average		26.2	1484	(0.392)	133	100	72	56	37	28
		1.0	49	(0.013)	17	24	19	16	13	10
Cold Temperature Period: December 1-February 24, 1978; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)										
1/5/78		12.0	1476	(0.390)	174	119	85	126	37	24
1/20/78	316	-	1563	(0.413)	98	59	29	26	16	13
1/25/78	323	-	1324	(0.350)	185	108	23	50	26	20
2/3/78	332	110	1476	(0.390)	174	104	33	26	18	22
2/10/78	337	11.0	1797	(0.475)	162	84	64	67	38	25
2/17/78	346	11.0	1457	(0.385)	203	87	53	69	26	18
2/24/78	353	12.0	1514	(0.400)	218	99	35	43	23	27
Average		11.4	1514	(0.400)	173	94	46	58	26	21
		.6	144	(0.038)	38	20	22	35	9	5

continued.

TABLE A-6. (continued)

		Total suspended solids (TSS) (mg/l)				
Date	Day	RBC influent	1	2	3	4
Low Loading Period:		March 9-April 6, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)				
2/14/77	6	161	244	279	626	234
3/16/77	8	128	340	212	180	202
Average		145	292	246	403	218
		23	68	47	315	23
Moderate Loading Period:		April 11-May 13, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)				
4/13/77	36	108	104	76	114	120
4/14/77	37	100	82	95	338	280
4/15/77	38	110	60	106	75	207
4/20/77	43	125	162	124	60	160
5/4/77	57	113	109	-	-	-
5/5/77	58	106	118	176	142	356
5/11/77	64	143	95	172	194	220
Average		115	104	125	117	224
		15	32	41	54	85
High Loading Period:		May 23-June 30, 1977; Baffles after Shafts 1, 2, 3 & 4 (6/16 & 6/17)				
6/1/77	85	143	134	170	-	568
6/3/77	87	113	80	376	123	382
6/9/77	93	175	-	-	-	-
6/16/77	100	105	127	237	88	147
6/17/77	101	107	155	300	126	128
Average		129	124	293	112	306
		30	32	88	21	209

continued.

TABLE A-6. (continued)

Date	Day	Total suspended solids (TSS) (mg/l)				
		RBC influent	1	2	3	4
Baffles after Shafts 2, 3 & 4 (6" clearance)						
6/22/77	106	136	130	373	30	183
6/23/77	107	137	114	161	104	97
6/24/77	108	138	104	174	132	97
6/29/77	113	-	-	-	-	-
7/1/77	115	95	102	151	77	83
Average		127	113	215	86	115
		21	12	106	43	46
Warm Temperature Period: July 18-September 23, 1977; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)						
7/20/77	134	139	104	312	76	64
7/21/77	135	138	112	334	132	133
7/22/77	136	-	112	504	89	154
7/27/77	141	108	94	243	91	163
Average		128	106	348	97	129
		18	9	111	24	45
8/4/77	149	110	93	170	74	110
8/5/77	150	105	99	205	70	117
8/10/77	155	99	-	-	-	-
8/11/77	156	100	191	538	83	79
8/12/77	157	79	237	553	49	327
8/17/77	162	179	120	164	94	106
8/18/77	163	157	149	140	114	-
8/19/77	164	133	192	383	262	356
8/24/77	169	-	135	165	104	151
8/25/77	170	167	94	136	81	90

continued.

TABLE A-6. (continued)

Date	Day	RBC influent	Total suspended solids (TSS) (mg/l) 1	2	3	4
8/26/77	171	121	100	192	280	111
8/31/77	176	141	148	168	137	116
Average		126	142	256	123	156
		32	48	158	77	100
Cold Temperature Period:		December 1-February 24, 1978; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)				
1/5/78		162	179	189	189	169
1/20/78	316	120	134	128	138	167
1/25/78	232	132	253	521	296	151
2/3/78	332	157	163	328	257	112
2/10/78	337	123	218	181	120	117
2/17/78	346	155	239	265	138	140
2/24/78	353	128	141	249	54	64
Average		141	190	266	169	131
		17	48	130	82	37

continued.

TABLE A-6. (continued)

		Dissolved oxygen (mg/l)				
Date	Day	RBC influent	1	2	3	4
Low Loading Period: March 9-April 6, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)						
2/14/77	6	8.5	4.6	4.6	4.4	4.2
3/16/77	8	8.4	4.4	4.1	3.9	3.7
Average		8.45	4.5	4.35	4.15	3.95
		0.07	.14	.35	.35	.35
Moderate Loading Period: April 11-May 13, 1977; Baffles after Shafts 1, 2, 3 (6" clearance)						
4/13/77	36	4.8	2.8	2.6	2.6	2.0
4/14/77	37	5.3	2.6	2.5	2.9	2.0
4/15/77	38	5.0	3.0	2.9	3.1	2.2
4/20/77	43	4.6	3.0	2.0	1.7	1.2
5/4/77	57	5.1	3.3	2.1	1.5	1.0
5/5/77	58	7.5	3.9	2.7	2.1	1.5
5/11/77	64	5.2	3.6	2.8	2.4	2.2
Average		5.4	3.2	2.5	2.3	1.7
		1.0	0.5	0.3	0.6	0.5
High Loading Period: May 23-June 30, 1977; Baffles after Shafts 1, 2, 3 & 4 (6/16 & 6/17)						
6/1/77	85	2.2	1.4	1.0	0.8	0.8
6/3/77	87	1.6	1.4	1.0	1.0	0.8
6/9/77	93	-	-	-	-	-
6/16/77	100	1.0	1.0	0.8	0.6	0.4
6/17/77	101	2.0	2.0	1.6	1.0	0.4
Average		1.7	1.5	1.1	0.9	0.6
		0.5	0.4	0.3	0.2	0.2

continued.

TABLE A-6. (continued)

		Dissolved oxygen (mg/l)				
Date	Day	RBC influent	1	2	3	4
Baffles after Shafts 2, 3 & 4 (6" clearance)						
6/22/77	106	2.2	1.4	1.4	1.2	0.4
6/23/77	107	1.8	1.4	1.2	1.0	1.0
6/24/77	108	1.8	1.2	1.0	0.8	0.4
6/29/77	113	3.4	1.6	1.4	1.0	0.4
7/1/77	115	0.8	0.8	0.8	0.6	0.4
Average		2.0	1.3	1.2	0.9	0.5
		0.9	0.3	0.3	0.2	0.3
Warm Temperature Period: July 18-September 23, 1977; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)						
7/20/77	134	3.2	0.8	0.8	0.6	0.4
7/21/77	135	0.4	0.2	0.2	0.2	0.1
7/22/77	136	0.6	0.4	0.4	0.4	0.2
7/27/77	141	0.2	0.3	0.4	0.2	0.4
Average		1.1	.43	.45	.35	.28
		1.4	.26	.25	.19	.15
8/4/77	149	0.4	0.4	0.3	0.3	0.4
8/5/77	150	0.4	0.4	0.4	0.4	0.6
8/10/77	155	1.0	0.6	0.6	0.6	0.8
8/11/77	156	1.2	0.6	0.6	0.4	0.6
8/12/77	157	1.0	0.6	0.6	0.6	0.8
8/17/77	162	1.0	0.7	0.4	0.3	0.3
8/18/77	163	0.8	0.8	0.5	0.2	0.2
8/19/77	164	1.1	0.7	0.7	0.4	0.4
8/24/77	169	1.8	0.8	0.2	0.2	0.3
8/25/77	170	3.4	1.2	1.2	1.2	1.4

continued.

TABLE A-6. (continued)

Date	Day	Dissolved oxygen (mg/l) RBC influent	1	2	3	4
8/26/77	171	4.2	2.0	1.6	1.4	1.8
8/31/77	176	-	-	-	-	-
Average		1.5	0.8	0.6	0.5	0.7
		1.2	0.5	0.4	0.4	0.5
Cold Temperature Period: December 1-February 24, 1978; Baffles after Shafts 1, 2, 3 & 4 (2" clearance)						
1/5/78		3.8	3.2	2.8	2.8	2.8
1/20/78	316	-	-	-	-	-
1/25/78	232	-	-	-	-	-
2/3/78	332	7.5	5.1	3.6	3.6	3.4
2/10/78	337	6.3	5.0	3.5	2.8	2.4
2/17/78	346	5.6	5.6	4.0	3.2	3.0
2/24/78	353	6.2	5.0	4.4	3.8	3.7
Average		5.9	4.8	3.7	3.2	3.3
		1.4	0.8	0.6	0.5	0.6

APPENDIX B

RBC STEADY STATE KINETIC MODEL

The model used in this study is applicable to the removal of soluble carbonaceous BOD in multi-stage RBC systems. Material balances are solved to determine substrate and oxygen levels in the effluent from each stage and in the attached biofilm. Mass transfer resistances, determined as a function of system operating conditions, are considered in both the liquid phase and biofilm, and the reaction rate is related to substrate and oxygen concentrations through the kinetic equations.

As shown on Figure B-1, the model assumes the media to consist of flat discs divided into stationary pie-shaped sectors. Each sector effectively acts as a flow-through mixed reactor, with advective transport of biomass and water across sector boundaries. Additionally, the model assumes that the liquid film remains static relative to the media as it moves through the air, and as it enters the tank the liquid film is stripped off and mixes completely with the wastewater. Oxygen transfer at the wastewater surface in the tank is considered negligible compared to the aeration which occurs on the disc surface.

Due to the significant concentration gradients which can exist normal to the disc surface, the biofilm is divided into layers, as shown on Figure B-2, for sectors above the water line. Biomass is conveyed through the stationary sectors at the volumetric rates Q_F, while the liquid film is transported at the rate Q_L.

Coupled Michaelis kinetics are used to simultaneously compute oxygen and substrate profiles through the fixed-film treatment process. The rate equations, which assume the reactions to occur exclusively in the biofilm layers, are as follows:

$$R_s = k \frac{S}{S + S_m} \qquad \frac{C}{C + C_m}$$

$$R_O = [a'k \frac{S}{S + S_m} + b'X_v] \frac{C}{C + C_m}$$

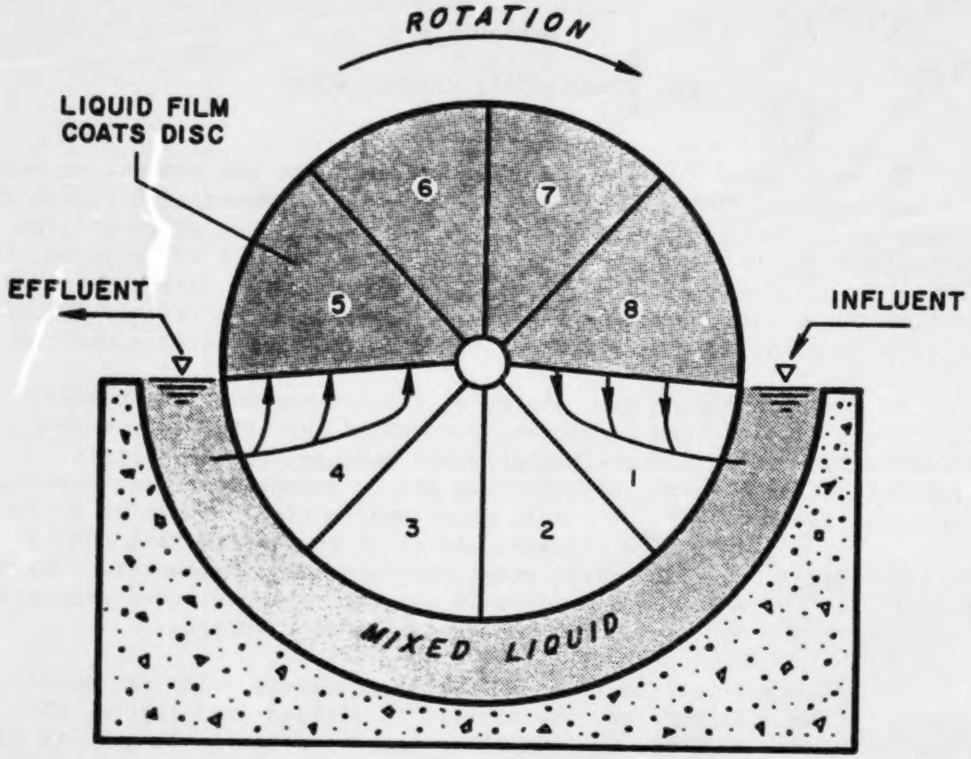

ROTATION
LIQUID FILM COATS DISC
EFFLUENT
INFLUENT
1
2
3
4
5
6
7
8
MIXED LIQUID

Figure B-1. Sketch of sectors in the RBC model

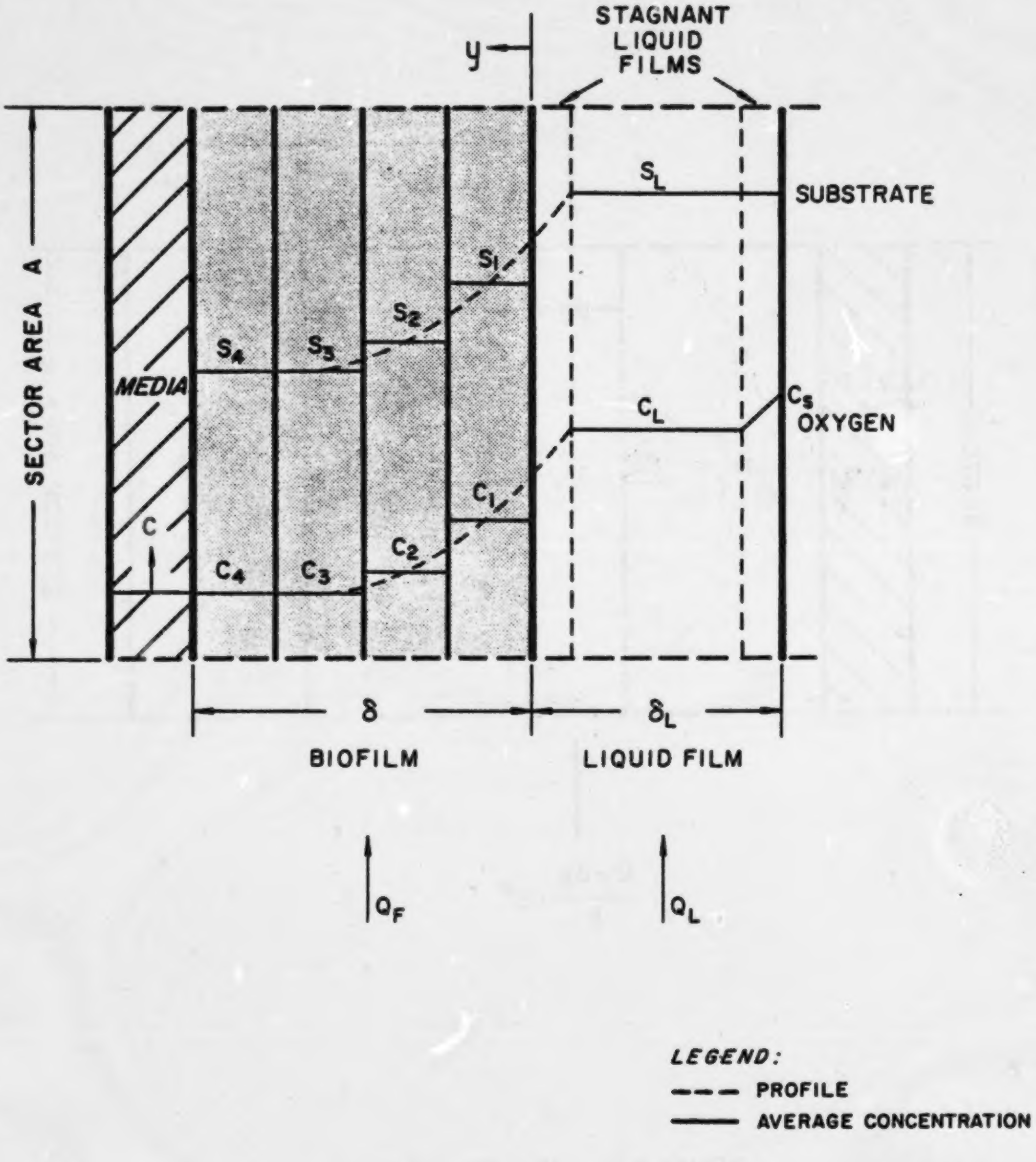

STAGNANT LIQUID FILMS
y
SECTOR AREA A
MEDIA
C
S_L
SUBSTRATE
S_1
S_2
S_3
S_4
C_L
C_S
OXYGEN
C_1
C_2
C_3
C_4
δ
δ_L
BIOFILM
LIQUID FILM
Q_F
Q_L
LEGEND:
PROFILE
AVERAGE CONCENTRATION

Figure B-2. Biofilm schematic diagram

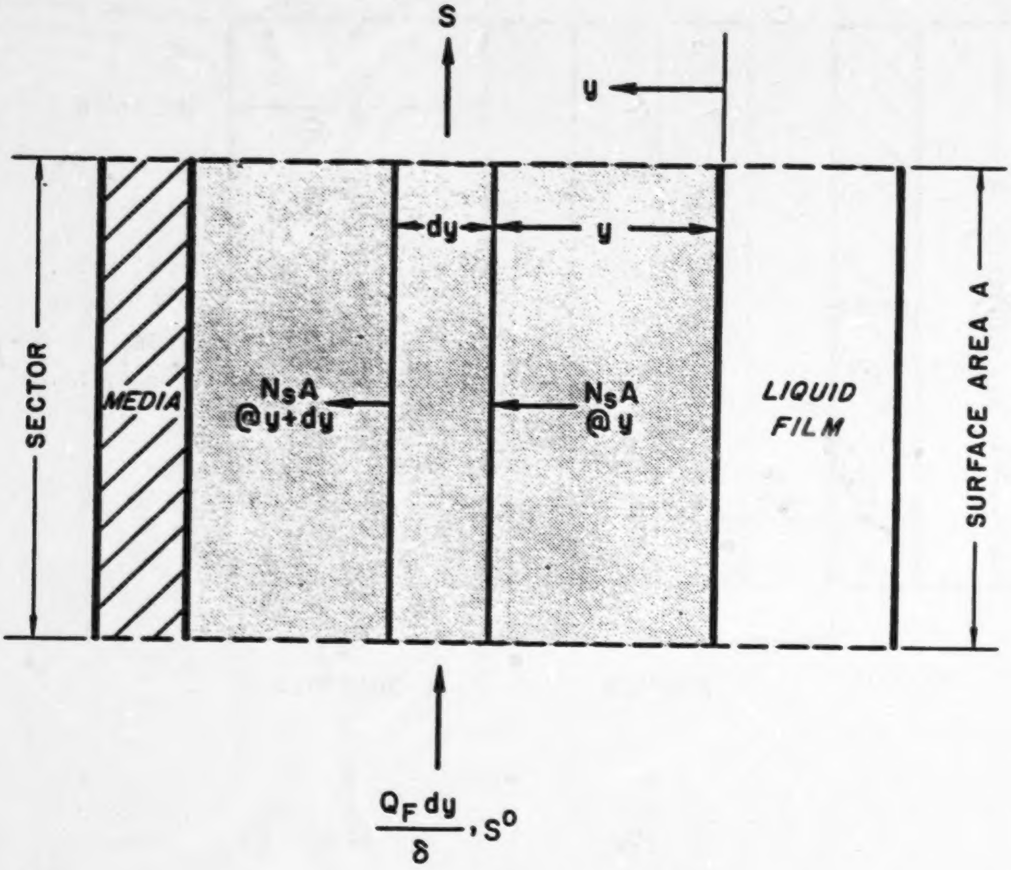

S
y
dy
y
SECTOR
MEDIA
N_sA @y+dy
N_sA @y
LIQUID FILM
SURFACE AREA A
$\frac{Q_F\,dy}{\delta}, S^o$

Figure B-3. Mass flux through infinitesimal slice of biofilm where R_s and R_o are the rates of substrate removal (mg/l/min BOD) and oxygen consumption (mg/l/min O2), respectively, and

S = substrate concentration (mg/l BOD)
C = oxygen concentration (mg/l O_2)
S_m = substrate Michaelic constant (mg/l BOD)
C_m = oxygen Michaelic constant (mg/l O_2)
k = maximum rate of substrate removal (mg/l/min BOD)
a' = oxygen utilization coefficient (mg O_2/mg BOD)
b' = endogenous reaction rate (mg O_2/mg VS/min)
X_v = biofilm volatile solids concentration (mg/l VS)

The maximum rate of substrate removal, k, is the combined term, $\mu X_v/Y$, where μ is the maximum specific growth rate, X_v is the biomass solids concentration, and Y is the organism yield coefficient. Because each of these is assumed constant in the model, a single rate constant (k) can be employed.

Further model simplification can be accomplished by using either zero order or first order kinetics with respect to substrate. Previous work(1) indicated that either one effectively predicted substrate removal through the system. For this particular model application, first order substrate removal kinetics were induced by setting a high Michaelis half rate constant of 10,000 mg/l. Thus the term,

$$k \frac{S}{S + S_m}$$

may be written (since $S_m \gg S$):

$$\frac{kS}{S_m}$$

The first order rate constant, k', reported herein can be defined as:

$$k' = \frac{k}{S_m} = \text{min}^{-1}$$

where k is the maximum rate of substrate removal used in the RBC model.

Substrate and oxygen concentrations are obtained by material balances on the biofilm layers, the liquid film, and the mixed liquor in the tank. Mass transfer through the biofilm is assumed to follow Fick's Law.

$$N_s = -D_s \frac{dS}{dy}$$

$$N_o = -D_o \frac{dC}{dy}$$

where D_s and D_o are the diffusivities of substrate and oxygen, respectively.

For the aerated sectors (see Figure B-2) a film of liquid is present between the atmosphere and biofilm. Transport through the liquid film-biofilm interface is described by the equations:

$$N_s = K_s\ (S_L - S_l)$$
$$N_o = K_o\ (C_L - C_l)$$

where K_s and K_o are the substrate and oxygen mass transfer coefficients, respectively. S_L and C_L are the average concentrations in the liquid film and S_l and C_l represent concentrations at the interface. At the liquid film-atmosphere interface, the transport rate of oxygen in the liquid is proportional to the difference between the saturation oxygen concentration, C_s, and C_L:

$$N_o = K_L\ (C_s - C_L)$$

Since the liquid film is assumed stagnant in the model, the mass transfer coefficients at both the biofilm-liquid and liquid-atmosphere interface are equal and designated as K_L.

In the tank, the wastewater is assumed to be completely mixed at concentration levels S and C. A mass transfer resistance exists at the biofilm interface, allowing the following substrate and oxygen flux equations:

$$N_s = K'_s\ (S - S_l)$$

$$N_o = K'_L\ (C - C_l)$$

The RBC model assumes that concentration profiles across the liquid film are approximately linear, with average concentrations of both substrate and oxygen occurring at the film center. From this, it follows that mass transfer coefficients are equivalent to the diffusivity divided by one half the liquid film thickness.

Liquid film thickness is computed from operating conditions based on the theory of plate withdrawal from liquids,

$$h_o = 6.85v^{2/3}$$

where v is the withdrawal velocity. An average withdrawal velocity at the centroid of mass (two-thirds media radius) was employed. To account for surface irregularities of the biofilm, a thickness of 25 was added to the h_o computed above. Thus the actual liquid film thickness is:

$$\delta L = h_o + 25$$

The mass transfer coefficients are related to δ_L:

$$K_s = \frac{D'}{\delta_L/2}$$

$$K_L = \frac{D_o'}{\delta_L'/2}$$

D_s and D_o are the diffusivities of substrate and oxygen in water, respectively, while $\delta_L/2$ represents the diffusion path length from average concentration to the interface concentration.

Figure B-3 graphically presents a material balance for substrate in the biofilm, for which the equation is:

$$D_s \frac{\delta^2 S}{y^2} + (S_o - S)\,\overset{Q_F}{A} - R_s = \frac{\delta S}{\delta t}$$

The first term represents the concentration gradient associated with diffusion through the biomass normal to the media. Advective transport through the stationary sector is described by the second term, and the third term is the reaction sink.

At the liquid-biofilm interface a convective boundary condition is employed where the mass transfer in the biomass is set equal to the flux through the adjacent liquid film.

$$-D_s \frac{\delta S}{\delta Y} = K_s (S_L - S), \text{ where } y = 0$$

Similar equations exist for oxygen. Additional mass balance equations are provided for the mixed liquor and the liquid film carried with the media above the water line. These equations, however, do not consider reaction sinks.

Solution of the model equations to obtain the desired substrate and oxygen concentrations is provided by an efficient finite-difference procedure, and is applicable to both dynamic and steady-state simulations.